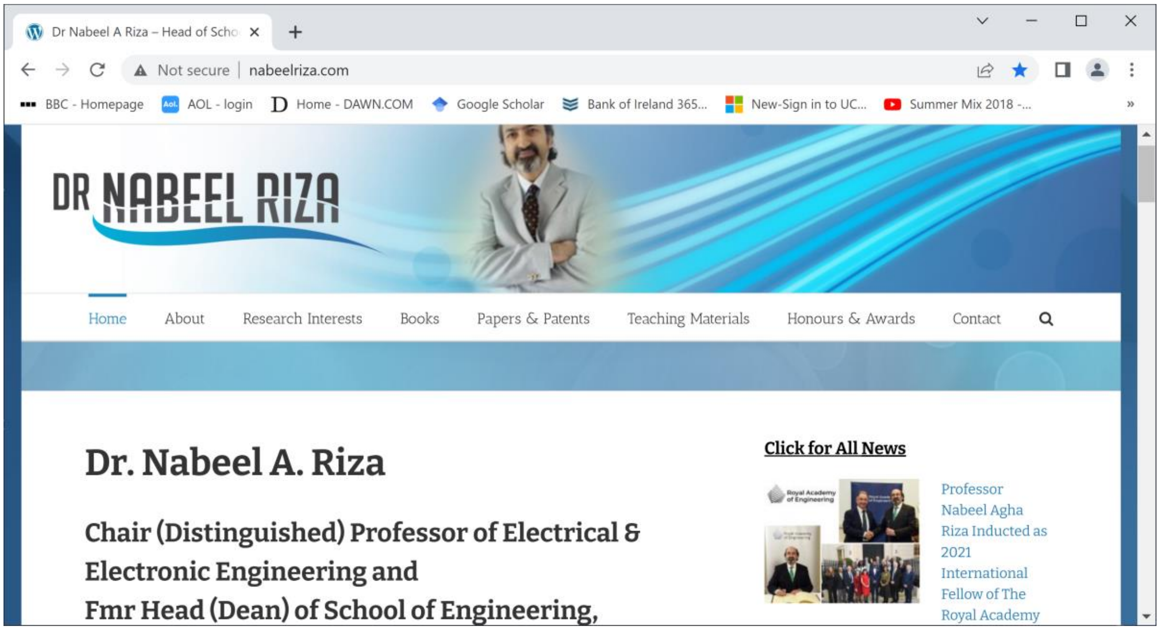
<u>**CURRICULUM VITAE**</u>

www.nabeelriza.com

***Note:* (Appendix at End of CV with Awards & Media Coverage)**



Nabeel A. Riza

Chair (Distinguished) Professor in Electrical & Electronic Engineering
Former Head (Dean) of the School of Engineering
University College Cork
Head, Photonics Information Processing Systems Laboratory
College Road, Cork, Ireland.
email: n.riza@ucc.ie

Education:

Ph.D. - Electrical Engineering, California Institute of Technology (Caltech), Oct. 1989

M.S. - Electrical Engineering, California Institute of Technology (Caltech), June 1985

B.S. - Electrical Engineering, Illinois Institute of Technology (IIT), August 1984

Research Interests and Internationally Acknowledged Applied Optics Multi-Disciplinary Contributions in:

(a) Cameras, Optical Imaging & 3-D Sensing (*e.g., Laser beam profilers and propagation analyzers, High Linear Dynamic Range Full Spectrum and Optical Power Handling Cameras/Imager Design, Lidar & Machine Vision Depth Sensing)*
(b) Communications (*e.g., RF Wireless mm-wave 5G/6G Base Station Multi-Beam Antenna Controls, Agile Energy Efficient Indoor & Outdoor Optical Wireless System Design and Fiber-Optic Communication Module Design, Agile Optical wireless high efficiency power delivery/energy harvesting*)
(c) Defense/Aerospace (*e.g., High Resolution RF Array Antenna Control and Wide Instantaneous Bandwidth Radar Signal processing*)
(d) Energy (*e.g., Design of Extreme Environment Physical Sensors- Temperature & Pressure sensors using Silicon Carbide*)
(e) Health/Biomedicine (*e.g., Designs for Fast 3-D Agile Beamforming Electronic Lensing-based Microscopy, Interferometric Angstrom Scale Bio-Sensing, Wavelength coded transverse and depth image sensors & endoscopy and Human Eye Vision Testing*)

Invited Books and Book Chapters

1. N. A. Riza, Editor, SPIE Milestone Series Book on "*Photonic Control Systems for Phased Array Antennas*", Vol.136, 1997. (A Reference Book for the Microwave Photonics Field)
2. N. A. Riza Co-Editor (with C. Cox & E. Ackerman from MIT Lincoln Labs.), SPIE Milestone Series Book on "*Analog Fiber-Optic Links*" , Vol.149, March 1998
3. N. A.Riza, Chapter on " Acousto-Optic Signal Processing," Wiley /IEEE Encyclopedia of Electrical & Electronics Engineering, Editor, J. Webster, March 1999.
4. N. A. Riza, Chapter on " Acousto-Optics," Comprehensive Dictionary of Electrical Engineering, CRC & IEEE Press, Jan. 1999.
5. **N. A. Riza, *Photonic Signals and Systems: An Introduction*, McGraw Hill, Jan. 23, 2013. (Undergraduate Textbook available for free download since May 16, 2020)**

Invited Tutorials & Short Courses:

1. At the 11th Topical Meeting on Optics of Liquid Crystals, Clearwater, Florida, Oct. 2005. (1 hour).

2. Short Course at the IEEE Photonics Society (LEOS) Annual Meeting, Turkey, Oct. 2009. (2 hours).

Publications and Patents Summary:

Peer-reviewed Journal Publications:	165
Conference Proceedings Publications:	201
Issued Patents:	**51**
GE Journal Publications	29
Total Publications & Patents	**446**
Invited Seminars/Lectures:	**92**

Google Scholar Link:
https://scholar.google.com/citations?user=xOxk_KUAAAAJ&hl=en&oi=sra

Research Funding: Over US $ 7.5 M support since joining academia in 1995.

YouTube Video Presentations by Nabeel A. Riza

- **Introducing the CAOS Smart Camera – Empowering Extreme Imaging**
  A Photonics Media USA Hosted Invited Webinar, 2017 (Duration 1 hour)

  https://www.youtube.com/watch?v=uhKvPnFXvBc

- CAOS Camera – Basic Principles
  Tutorial Short Animation Video (Duration 3 minutes)

  https://www.youtube.com/watch?time_continue=13&v=oQOa_zfHchU

- Compressive Sensing using the Agile Pixel Camera
  Tutorial Short Animation Video (Duration ~3 minutes)

  https://www.youtube.com/watch?v=6t-m9ypKaRQ

- Agile Pixel Camera
  Tutorial Short Animation Video (Duration 3 minutes)

  https://www.youtube.com/watch?v=CyPjlD8Z7N4

- CCD and CMOS Multi-pixel Cameras
  Tutorial Short Animation Video (Duration 3 minutes)

  https://www.youtube.com/watch?v=jP2A3WvhKqQ

- Inventing with Light – A Personal Journey (LUMS School of Engg & Science and Khwarizmi Society Invited Lecturer 2016 (Duration 1 hour)

  https://www.youtube.com/watch?v=H1-O5RoCf9M&feature=youtu.be

- Nabeel Agha Riza 2019 Edwin H. Land Medal Presentation Ceremony at IS&T CIC27, Sorbonne Univ., Paris, France. (Duration 3 minutes)

  http://nabeelriza.com/nabeel-agha-riza-presented-the-2019-edwin-land-medal-at-ist-cic27-sorbonne-univ-paris/

Research Related Awards & Honors:

- **2022 Fellow Award, International Society for Imaging Science & Tech. (IS&T)**

  The Fellow Award of the IS&T is awarded for outstanding achievement in imaging science or engineering. Prof. Riza Fellow Award citation states: " for invention of the extreme linear dynamic range full spectrum CAOS-CMOS camera and other high impact inventions in image engineering." A maximum of 5 Fellow awards can be presented annually. A triangular, engraved plexiglass statuette is presented to recipient. Previous reknown awardees include American landscape photographer Ansel Adams and optical imaging inventor Stephen A. Benton.

- **2022 Fellow Award, Asia-Pacific Artificial Intelligence Association (AAIA)**

  The Fellowship of the Asia-Pacific Artificial Intelligence Association (AAIA) by invitation only acknowledges Prof. Riza's high level of achievement as an internationally and publicly recognised researcher in optical communications and sensing technologies, including early use of Artificial Intelligence (AI) methods in optical sensors. https://aaia-ai.org/fellows?words=Nabeel%20A.%20Riza

- **2021 Inductee as International Fellow, Royal Academy of Engineering (UK)**
  Prof. Riza is elected an International Fellow as a global prize-winning inventor of light-based technologies. The Royal Academy of Engineering is UK's National Academy of Engineering. Prof. Riza was one of four individuals selected in 2021 for the International Fellow Membership honor which included decorated US academic Prof. Cato T. Laurencin whom US President Obama in 2016 presented the US National Medal of Technology & Innovation, USA's highest national award in technology innovation. Prof. Riza also became only the eighth person in the Republic of Ireland's 100 years history to receive this high UK honour. The Royal Academy Membership is diverse and represents UK and the world's top engineers from the business, government and educational sectors, including Academy Honorary Fellow Lewis Hamilton who is a seven-time Formula One World Champion representing Mercedes-AMG Petronas Motorsport. Notable International Fellows include 2014 Physics Nobel Laureate UCSB Professor Shuji Nakamura (2019 USA), 2018 Chemistry Nobel Laureate Caltech Professor Frances Arnold (2018 USA) and former Stanford University President & Computer design pioneer Professor John Hennessy (2017 USA).

- **2021 Fellow Award, Institute of Physics**
  The Fellowship of the Institute of Physics (FInstP) is an award granted by the Institute of Physics (IoP) which indicates a very high level of achievement in physics and an outstanding contribution to the profession. 2020 marked the 100th anniversary of the founding of the Institute of Physics in London, UK. Prof. Riza is acknowledged by IoP

Fellow award for his world leading research and teaching contributions in applied physics including study of high temperature silicon carbide materials for sensing to precision high stability optical interferometry techniques.

- **2020 Inductee, Royal Irish Academy**
  The highest honor awarded to scholars in Ireland (including N. Ireland, UK) across all disciplines that includes physical sciences, engineering, social sciences, mathematics and computer science, social sciences, law, humanities, and medicine and biological sciences. The RIA was founded in 1785 and past Presidents include the famed Irish mathematician Sir William Rowan Hamilton. Distinguished and renowned RIA members include Mary Robinson, former President of the Republic of Ireland and Nobel Prize winner in Literature, William B. Yeats and **Nobel Prize winning physicists Erwin Schrödinger** and Ernst T. S. Walton. Honorary members include Nobel Laureates physicist Steven Weinberg (U-Texas), physicist Murray Gell-Mann (Caltech), chemist Robert Grubbs (Caltech), economist Amartya Sen (Harvard), & neuroscientist John O'Keefe (UCL). Professor Riza (***the only engineer in the 23 inductees for 2020***) is acknowledged *for his contributions to both research and education in Ireland over a 9 years period and for 30 years international career as a world leading photonics inventor impacting key areas of technology in imaging, communications, energy and aerospace systems*

- **2019 OSA/IS&T Edwin H. Land Medal**
  Recognizes pioneering work empowered by scientific research to create inventions, technologies, and products. Also considered the world's leading Prize in Imaging Science and Technology. Awarded to N. A. Riza with citation: " *for the invention and commercialization of pioneering macro- and micro-scale imaging techniques across RF and optical wavelengths, and the education and mentoring of distinguished scientists and engineers*." Winners include G. Smith and W. Boyle who were awarded a **Physics Nobel Prize for CCD camera** invention and **Eric Fossum (2020 Edwin Land Medalist & 2017 Queen Elizabeth Prize in Engineering), inventor of the CMOS sensor camera** used in millions of phones. Dr. Edwin Land was the inventor of the Polaroid Camera and founder of Polaroid Corporation. OSA: The International Optical Society; IST: The International Society for Imaging Science and Technology.

- **2018 IET Engineering Achievement Medal for Photonics**
  (1 of 5 in world selected to receive this engineering award, presented Nov., 2018, London, UK)**.** Recognizes Prof. Riza's inventions including fiber-optic light control modules deployed in the global internet. IET (formerly IEE UK) is the Institute of Engineering and Technology, the 2nd Largest International Engineering Society in the world (IEEE is first) with head quartered in London.

- **2018 AutoSens Game Changer Technology Finalist Award** for the CAOS camera invention. Other finalists Intel Corp. USA and Robert Bosch Corp. Germany

- **2018-2022 United States (US) National Academy of Inventors (NAI) Advisory Committee**

- **2016 United States (US) National Academy of Inventors (NAI) Fellow Inductee.**

- **2016-2022 Royal Irish Society (RIA) Engineering and Computer Science Committee Member**

- **2015 Honorary Fellow Award (Hon. FIEI) from the Engineers Ireland Society.** It is the Highest Distinction of the Society, awarded by presidential invitation only, and recognises true leaders of the engineering profession who are highly skilled, contribute to the future of engineering and promote excellence.

- **2015 Professional Chartered Engineer (CEng) Award from the Engineers Ireland Society.** (Awarded by presidential invitation of Engineers Ireland Society)

- **2012 European Optical Society (EOS) Fellow Award** for inventions of extreme environment optical sensors and imaging instruments for coherent and incoherent light. In 2012, amongst the 71 Fellows of the Society since its founding in 1990.

- **2011 IET Fellow Award** for Distinction in Photonics Research and Leadership in the Electrical Engineering Profession**.**

- **2011 American Society of Engineering Education (ASEE) Senior Faculty Fellow Award** for Research in Hybrid RF-Optical Sensors

- **2010-2011 IEEE Photonics Society (LEOS) Distinguished Lecturer Award** (Renewed from 2009-10: one of 5 world-wide) for Research in Hybrid Optical Sensors for Industrial Applications

- **2009-2010 Ireland Science Foundation Ernest T. S. Walton Award as International Distinguished Visiting Scholar to Ireland.** (Dr. Walton is Ireland's only Nobel Prize winner: 1951 in Physics; The Award is Internationally Peer Reviewed) **(one of 16 scholars world-wide covering all fields of science, medicine, & engineering)**

- **2009-2010 IEEE Photonics Society (LEOS) Distinguished Lecturer Award** (one of 5 world-wide) for Research in Extreme Optical Sensors for Gas Turbines in Power Plants

- **2008 German Berthold Leibinger Innovation Prize Finalist Distinction Award** (one of 8 world-wide - award presented Stuttgart, Germany at TRUMPF Co.) for Innovation in Applied Laser Technology) For: Invention of Laser Profiler/Imager

- **2008 Distinguished Alumni Professional Achievement Award from the Illinois Institute of Technology**

- **2007-2008 European Union (EU) Erasmus Mundus Visiting Scholar Professorship Award.** One of three winners worldwide selected by EU Optical MSc Course Program. Visiting Optica Group, Faculty of Applied Sciences, TU-Delft, Institute of Optics-Univ. Paris, & Univ. Jena-Germany.

- **2007 Institute of Electrical & Electronic Engineers (IEEE) Fellow Award**
  Citation: For contributions to acousto-optic, liquid crystal, and micromirror device applications in photonic signal processing and controls"
  IEEE Society: Lasers and Electro-Optics Society (LEOS)

- ***International Commision for Optics (ICO) 2001 International Prize in Optics and 2001 Ernst Abbe Medal from Carl Zeiss Foundation-Germany***

(Generally Considered the Highest International Prize in Optics for Scientists under 40 years)
See ICO Prize Details and winners at: https://www.e-ico.org/node/28
Related Distinctions:

- First South-Asian Origin Scientist to Win ICO Prize & Abbe Medal
- First Caltech Alumnus to win ICO Prize & Abbe Medal
- First Illinois Inst. of Tech. Alumnus to win ICO Prize & Abbe Medal
- First Student-Ph.D. Advisor Team to Win ICO Prizes (Advisor: D. Psaltis, ICO Prize 1989)
- First Grand Advisor (Psaltis ICO 1989)-Advisor (Riza ICO 2001)-Riza Student Team (Sarun Sumriddetchkajorn Abdus Salam ICTP-ICO Award 2005) to win ICO based International Awards.

- **1998 Fellow of the Optical Society of America (OSA)**

Citation: For pioneering and sustained optical inventions in photonic control systems for phased array antennas

- **1998 Fellow of the International Society for Optical Engineering (SPIE)**

Citation: For specific achievements in the area of photonic information processing systems, including the invention of scanning acousto-optic interferometers, wideband acousto-optic signal processors, liquid crystal optical switches and programmable lenses.

- ***2004 LaserFocusWorld Commendation Award for Excellence in Technical Writings August 2004. (Related to Nuonics,Inc. Beam Profiler Technology)***

- Chapter Chair, IEEE Lasers and Electro-Optics Society (LEOS) Orlando Section 1996-2002
- Appointed Vice President IEEE for Lasers and Electro-Optics Society (LEOS) 2002-2005
- Senior Member IEEE 1994
- General Electric Company Corporate R & D Three Patent Medals (1994 Gold, 1993 Silver, 1991 Bronze Patent Medals) Gold is for 20 patents.

- General Electric Company Corporate R & D Publications Award 1994 (over 75 publ.)
- General Electric Company Corporate R & D New Start Research Award 1990
- International Society for Optical Engineering:SPIE Student Award 1987
- Caltech Scholarships 1984-89
- Illinois Institute of Technology Alumni Association Academic Achievement Award 1984 (Amongst top 3 seniors in Graduating Class of Entire University)
- Elected Member Phi Eta Sigma 1982 (Freshman Honor), Tau Beta Pi 1984 (National Engineering) and Eta Kappa Nu 1982 (Electrical Engineering) Student Honor Societies
- Illinois Institute of Technology Merit Scholarships 1982-84
- Double Distinction in Advanced (A) Level Mathematics, Cambridge University (U.K.) Overseas Higher Senior Cambridge Program 1980.

Teaching and Education Awards:

- The International Optical Society (OSA) International Traveling Professor Award 2016.
- Optical Society of America (OSA) International Traveling Professor Award 2009.

- EU Eramus Mundus OptSc Program 2008 Univ. of Jena, Germany Optics Summer School Carl Zeiss Student Project Prize for 4-student Team mentored by Prof. Riza.

- Optical Society of America (OSA) International Traveling Professor Award 1999.

- Graduate Research Student Awards to Group Members:

  1997 New Focus Optics Essay Prize (N. Madamopoulos)

  1998 OSA-New Focus Prize (N. Madamopoulos)

  1997 SPIE Scholarship (N. Madamopoulos)

  2000 IEEE LEOS Student Fellow Award (Sarun Sumriddetchkajorn)

  2000 OSA-New Focus Prize (Sarun Sumriddetchkajorn)

  2000 SPIE D.J Lovell Prize (S.Sumriddetchkajorn - Highest graduate research honor)

  2000 Best Thai Citizen Ph.D. Dissertation Award

  2003 SPIE Scholarship (Zahid Yaqoob)

  2003 Best CREOL Ph.D. Dissertation Award (Z. Yaqoob)

  2004 IEEE LEOS Student Fellow Award (Muzammil Arain)

  2004 SPIE Scholarship (Muzammil Arain)

2004 Best Young Scientist Award Thailand (Sarun Sumriddetchkajorn)

2005 Abdus Salam ICTP/ICO Young Scientist Award (Sarun Sumriddetchkajorn)

2005 OSA-New Focus/Bookham Prize (Sajjad Khan)

2005 IEEE Orlando Section Best Graduate Student Research Award (Sajjad Khan)

2009 SPIE Scholarship (Mumtaz Sheikh)

2010 SPIE Scholarship (Syed Azer Reza)

2014 SPIE Fellow Award (Sarun Sumriddetchkajorn)

2016 OSA Paul F. Forman Team Engineering Excellence Award (M. Arain as Part of the Advanced LIGO Team contributing to the 2017 Physics Nobel Prize for Gravitional Wave Detection)

2016 Special Breakthrough Prize in Fundamental Physics (M. Arain as Part of the Advanced LIGO Team contributing to the 2017 Physics Nobel Prize for Gravitional Wave Detection)

2016 USA Fulbright Scholar Award (Mumtaz Sheikh)

2016 OSA Fellow Award (Sarun Sumriddetchkajorn)

2022 President's Medal – Pakistan National Honour: Tamgha-e-Imtiaz in Science & Technology Education (M. Junaid Mughal)

2025 Best Masters Thesis Prize (Ms. Orla M. Cowhig)

2025 Best Overall Masters Student -Wrixon Medal (Ms. Orla M. Cowhig)

- IEEE LEOS Educational Grants

Two IEEE LEOS Educational Grants of $ 2445 and $ 1495 awarded to the CREOL IEEE LEOS Student Chapter that I started in 1995 and now act as the advisor. The first project was "The Color Laser Scanner" and the second one is the " Laser Communication Link" project. Both projects have both undergraduate and graduate CREOL students involved from various departments.

- Illinois Institute of Technology Student Counselor Recognition Award 1984

Service Awards and Distinctions:

- Recipient as Chair of the 1999 IEEE LEOS Chapter of the Year award

- Recipient as Chair of the 1998 IEEE LEOS Most Innovative Chapter award

- Recipient as Chair of the 1997 IEEE LEOS Most Innovative Chapter award

- Recipient as Chair of the 1996 IEEE LEOS Highest Membership Increase Chapter award

- 2002-2005 served as Vice President of IEEE Photonics Society stressing student activities. As IEEE LEOS Orlando Section Chair, **Established the First IEEE LEOS/Photonics Society Student Chapter in Spring of 1996** (Plaque Commemorating the Student Chapter Formation with 16 Student Founding Member Names installed in Newly Built CREOL Bldg). **Three decades later as of Dec.2021, there are 71 IEEE Photonics Society Student chapters active throughout the world.**

Optics & World Media Press Recognition:

- OSA and IS&T Name Nabeel Agha Riza the 2019 Edwin H. Land Medal Recipient. March 29, 2019.
- "Beam Characterization: CAOS camera images laser beams with extremely high dynamic range," by John Wallace, Sr. Editor, Test & Instrumentation section, Laserfocus World Magazine, Nov.1, 2018.
- Winners of the 2018 IET Achievement Medals Announced at the IET Awards Ceremony, Nov. 14, 2018, The Brewry, London, UK.
- "CAOS Smart Camera captures bright targets in CDMA-mode," by Gail Overton, Sr. Editor, Test & Instrumentation section, Laserfocus World Magazine, Dec.27, 2017.
- "H-CAOS Camera," Selected as a 2016 Breakthrough in Imaging for the OSA Optics & Photonics News (OPN) Magazine, Optics in 2016 Special Issue, Dec., 2016.
- "CAOS-CMOS camera has 1000X better dynamic range than CMOS Camera alone," World News Section, Laserfocus World Magazine, August Issue, 2016.
- "Coded Access Optical Sensor Boosts CMOS/CCD Performance," Photonics.com media press release, June 20, 2016 (www.photonics.com)
- "Image captured by CAOS Camera of an extreme contrast and brightness target," June 16, 2016. http://www.opli.net/

- "Analog-Digital Photonics 3-D Irradiance Mapping ," N. A. Riza, International Society of Optical Engineering (SPIE) New Room Feature Article, August 26, 2010. (www.spie.org)
- "Hybrid Optical Sensors for Extreme Environments," N. A. Riza, International Society of Optical Engineering (SPIE) New Room Feature Article, March 23, 2010. (www.spie.org)
- "All-digital and hybrid analog-digital beam profiling technology," N. A. Riza, German Photonik Magazine, Metrology Feature, Feb.2009. (www.photonik.de)
- "No Moving Parts Axial Scanning Confocal Microscopy," Research Article Selected for the OSA Optics & Photonics News (OPN) Magazine, Optics in 2008 Special Issue, Dec., 2008.
- "Taking Advantage of the Digital Realm: A Paradigm Shift in Laser Beam Profiling Technology," N. A. Riza, Laser Focus World Magazine, August 2004.
- " No-moving parts optical set-ups scan bar codes," Daniel S. Burgess, Photonics Research, Photonics Spectra Magazine, pp.134-135, May 2004.
- " All digital profiler handles high power beams," John Wallace, Optoelectronics World News Section, pp.23-25, Dec. 2002 Issue, Laser Focus World Magazine. www.laserfocusworld.com
- "Scientists explore the outer limits," Analysis Section, pp.17-18, March 2002 Issue, Fibre Systems Europe Magazine.
- " Nuonics rings changes on VOAs," Technology Focus Section, Special report on optical components, p.14, March 2002, Fibre Systems Europe Magazine.
- " Variable attenuator for fast response high optical power applications," Optical Engineering Section, p.41, Optics in 2002 Special Issue of OSA Optics & Photonics News (OPN) Magazine, Dec., 2002.
- " Sound waves shake up fiber-optic components," Emerging Technologies Section, pp.21-23, Nov./Dec. Issue 2002, Fibre Systems International Magazine. Also pp.29-32, Sept.2002 Issue, Fibre Systems Europe Magazine. http://fibers.org
- " New ventures strive to air their message," J. Devaney, pp.19-20, Analysis Section, April 2002 Issue, Fibre Systems International Magazine.

- **MEMS pioneer wins ICO award** , 14 March 2002 "Nabeel Riza has won the International Commission for Optics' annual prize." Institute of Physics (IOP), UK Press Release. http://optics.org
- Optics Professor is World Class, by S. Loden, Univ. Press Release, Oct.21, 2001.
- Pride in Accomplishments, Press Release, The 55th National Conference on the Advancement of Research, Dec. 2002.
- The ICO Award Winners, Prizes and Awards in Physics: CIRS. http://www.cirs.net/awards/physics/physicICOprizes.htm
- "High Speed Multiwavelength MEMS Fiber-Optic Attenuator," Research Article Selected for the OSA Optics & Photonics News (OPN) Magazine, Optics in 1999 Special Issue, Dec., 1999.
- "High Speed Multiwavelength Photonic Switch," Research Article Selected for the OSA Optics & Photonics News (OPN) Magazine, Optics in 1998 Special Issue, Dec., 1998.
- "High Speed Scanning Interferometer for Scientific & Industrial Applications" Research Article Selected for the OSA Optics & Photonics News (OPN) Magazine, Optics in 1997 Special Issue, Dec., 1997.
- "Photonic Signal Processing for Biomedical and Industrial Ultrasonic Probes" Research Article Selected for the OSA Optics & Photonics News (OPN) Magaz., Optics in 1996 Special Issue,Vol.7, No.12, pp.22-23, Dec., 1996.
- "Fault-tolerant fiber attenuator using micromirrors" Research Highlighted in World News Section of the Laser Focus World Magazine , Oct., 1999.
- "Fiber Enables Photonic Time Delay Signal" Research Highlighted in World News Section of the Laser Focus World Magazine , p.28, Sept., 1996.
- "Electro-Optic Controller for Phased Array Antennas," SPIE Optoelectronics (OE) Reports Newsletter Article, No.121, Jan.,1994.

Professional Positions Held:

Duration: August 2011 to Present
Position: **Chair (Distinguished) Professor** of Electrical & Electronic Engineering
University College Cork, Ireland

Duration: June 2013 to Sept. 2016
Position: **Head (Dean) of The School of Engineering**
University College Cork, Ireland.

Duration: August 2011 to May 2013
Position: **Head of Department** of Electrical & Electronic Engineering
University College Cork, Ireland
& Associate Academic Member Tyndall National Institute
University College Cork, Ireland

Duration: Summer 2009 and Summer 2010
Position: E. T. S. Walton **Distinguished Visiting Full Professor**
National University of Ireland, Galway, Ireland.

Duration: Summer 2007 and Summer 2008
Position: EU Erasmus Mundus **Scholar Visiting Full Professor at Optica Group**
Delft University of Technology (TU Delft), Netherlands.

Duration: 2001 – May 2011
Position: **Full Professor**
CREOL, USA

Duration: Jan.2001- Aug. 2011 (on 50% part leave from CREOL)
Position: **Founder and President**
Nuonics, Inc., USA (Start-Up Company)

Duration: Feb.1 1995 to 2001
Position: **Associate Professor of Optics and Electrical & Computer Engineering**
CREOL, USA.

HighLights: Trained international award winning Ph.D. students including 2005 ICO/Abdus Salam ICTP Award Winner, three OSA-New Focus Prizes, One SPIE D. J. Lovell Prize (highest award from SPIE), three IEEE LEOS Student Fellows and several SPIE Scholarships

In 1995, Won as PI $ 1.1 M USA grant for R & D on a Photonic Controller for an Advanced Phased Array Radar

In 1998, founded high technology small business Nuonics, Inc. via Riza inventions. Established operations and presently continuing commercialization efforts.

In 2000, Won as PI $ 900 K USA grant to develop a new generation of scanner technology called MOST

In 2004, Won as PI $ 1.25 M USA grant to develop a new generation of extreme environment optical sensor technology

In 2006, Won as PI, one of six competitive USA DOE University Energy Research Program Grants to study a new generation of extreme environment optical sensor technology for clean energy coal-fired power plants.

In 2011, awarded grant of Euro 400 K as PI from Irish Government UCC Research Sponsorship to conduct research in ICT and sensors.

In 2017, awarded a Half a Million Euro grant as PI from Enterprise Ireland (EI) and European Union (EU) European Regional Development Fund to develop and commercialize the CAOS Smart Camera technology.

Duration: Nov., 1989 to Jan.,1995
Position: **Lead Scientist & Project Manager**
Optically Controlled Radar Project
General Electric Corporate Research and Development Center, Schenectady, New York, USA

HighLights: Introduced, Organized, Managed, and Secured a $ 2 Million, 4 year Effort to Develop Novel Antenna Controllers & Subsystems for GE Aerospace

Made the Key Technical Breakthroughs for meeting the Changing Business Goals described extensively in over 75 publications & 20 patents

Duration: Sept., 1984 to Oct., 1989
Position: **Research & Teaching Assistant** (Doctoral Candidate)
Optical Information Processing Group, Electrical Engineering Dept.
California Institute of Technology, Pasadena, U.S.A.

HighLights: Amongst the earliest contributions to the field of "Photonics & Phased Array Systems (PAPAS)"

First Ph.D Thesis in this field

Specifically, introduced the use of Ultra-Stable Coherent Optics for Reversible Transmit/Receive Mode Optical Control of Phased Array Antennas

Invented an ultra-stable optical interferometer called the "In-line Acoustooptic Interferometer, " that has proved itself as a high performance optical system for key signal processing tasks such as RF Correlation, Convolution, I-Q Processing, & Wideband Spectrum Analysis.

Teaching Activities

Taught both graduate and undergraduate classes that include:

1. Photonic Signal Processing (Graduate)
2. Wave Optics (Graduate)
3. Optical Engineering (Undergraduate)
4. Engineering Electromagnetics (Undergraduate)
5. Photonic Signals and Systems (Undergraduate) – via N. A. Riza authored Book.
6. RF Transmission Lines (Undergraduate)

Supervised Visiting Professors, Post-Doctoral Staff, and Ph.D., Master's, and BS level students that include:

1. Nicholas Madamopoulos (MS. & Ph.D. student; Ph.D awarded 1999)
2. Sarun Sumriddetchkajorn(MS & Ph.D. student; Ph.D awarded 2000)
3. Jian Chen (MS student, MS awarded 1998, Later received PhD from MIT)
4. Dr. Jinkee Kim (Postdoc 1996)
5. Dr. Shifu Yuan (Postdoc 1997-98)
6. Prof. Azhar Rizvi (Visiting Professor 2000)
7. Yu Huang (MS student, MS awarded 2001)
8. Dr. Deepak Sengupta (Postdoc 2000)
9. Zahid Yaqoob (MS awarded 2001, Ph.D. awarded 2003)

10. Sajjad Khan (MS awarded 2002, Ph.D. Nov. 2005)
11. Muzamil Arain (MS awarded 2002, Ph.D. Summer 2005)
12. Mirenda Stratton (1997 NSF undergraduate REU scholar from Univ. of Maryland-College Park)
13. Jeff Steedle (1998 NSF undergraduate REU scholar from Univ. of Notre Dame)
14. Doug Jorgenson (2002 NSF undergraduate REU scholar Univ. of Illinois-Urbana)
15. Ruud Gileson (2000 International Master Research Project, Technical Univ. of Eindhoven, Netherlands)
16. Martin van Buren (2002 International Master Research Project, Technical Univ. of Eindhoven, Netherlands)
17. Fredrico Pierra (2002 International Master Research Project, Imperial College London, UK)
18. Jason Karp (2003 NSF undergraduate REU scholar from Univ. of Miami)
19. Marten Bakker (2003 International Master Research Project, Technical Univ. of Eindhoven, Netherlands)
20. Tiffany Metzig (2004 NSF undergraduate REU scholar from CREOL)
21. Matteo Gentili (2006 International Masters Research Project, University of Ancona , Italy)
22. Farzan Ghauri (2003 MS Awarded, Ph.D. Aug.2007)
23. Mumtaz Sheikh (2007 M.S., Ph.D. Dec. 2009)
24. Syed Azer Reza (2007 M.S., Ph.D. April 2010)
25. Philip Marraccini (2011 M.S., PhD May 2013)
26. Barry Thompson (BE Thesis 2014)
27. Bobby Bornemann (BE Thesis 2015)
28. Mehdi Riza (Undergrad Research 2015)
29. M. Junaid Amin (Ph.D. Sept. 2016)
30. Nathan Mayes (BE Thesis 2016)
31. Juan Pablo La Torre (Ph.D. Sept. 2017)
32. Mohsin Ali Mazhar (2021, Ph.D.)
33. Dr. Muhammed Amiri (2018, Post-Doc)
34. Conor Russell (BE Thesis 2018)
35. Dr. Mojtaba Montezeri (2018, Post-Doc)
36. Dr. Nazim Ashraf (2019-2020, Post-Doc)
37. Ms. Orla M. Cowhig (2024-25, Masters Thesis)

Ph.D. Dissertation Committee Member for the Following Non-Group Students:

1. Muhammed Al-Mumin (Advisor: G. Li)
2. Walleed Mohamed (Advisor: E. Johnson)
3. M. Mujat (Advisor: A. Dogariu)
4. Nan Zhang (Advisors: D. Polla and S. Roorda; Univ. of Montreal-Canada)
5. Claire Fan (Advisor: S. T. Wu)
6. Fang Du (Advisor: S. T. Wu)
7. Yi-Hsin Lin (Advisor: S. T. Wu)
8. Yung-Hsun Wu (Advisor: S. T. Wu)
9. Shinwok Lee (Advisor: P. Delfyett)
10. Meizi (Advisor: S. T. Wu)
11. H. Cheng (Advisor: S. T. Wu)
12. Likai Zhu (Advisor: G. Li)
13. Pham Quang Thai (Advisor: A. Alphones, Nanyang Tech. Univ., Singapore)
14. Brian Fitzgibbon (Advisor: M. P. Kennedy) 2013
15. Kevin Hartley (Advisor: J. Hayes) 2013
16. Ehsan Sooudi (Advisor: John McInerney) 2013
17. Hyman Nabil Shanan (Advisor: M. Peter Kennedy 2016)

Teaching/Educational/Professional Service Activities

1. 2017-2022 Member of the Irish Royal Academy Engineering Committee
2. 2017-2022 Advisory Selection Committee Member, US National Academy of Inventors
3. IEEE LEOS Vice President for Memberships, 2002-2005.
4. Faculty Advisor to the IEEE LEOS CREOL Student Chapter 1996-2002
5. Chair, IEEE LEOS Orlando Chapter 1995-2002.
6. Organizer of the CREOL IEEE LEOS Distinguished Seminar Series 1996-2002
7. Guest Presentation at the Summer 1997 and 1998 CREOL NSF REU Program.
8. Invited Member of OSA A. Lomb Medal Committee 2005 and 2006.
9. Invited Member IEEE LEOS Distinguished Lecturer Award Committee 2005 and 2006.

10. Selected on basis of scientific contributions in Information Optics as an International Official Nominator for the 2009 Japan Kyoto Prize in Advanced Technology.

11. Invited Member OSA Esther Hoffman Beller Medal Committee 2009 and 2010.

12. Appointed **Associate Editor of International Journal of Optomechatronics**, Francis Taylor, 2009.

13. Appointed **Associate Editor of International On-Line Journal of 3-D Research**, 2009.

14. Appointed **on the Editorial Board of International On-Line Journal of Optics**, 2012. Basel, Switzerland (http://www.mdpi.com/journal/optics, ISSN 2304-6732).

15. Appointed on the **Editorial Board of Springer Nature Journal of the European Optical Society**- Rapid Publications (JEOS-RP), 2013. (www.jeos.org).

16. Appointed on the Selection Committee of the European Optical Society (EOS) Fellow Award 2014.

17. Appointed reviewer European Research Council (ERC) Starter Award 2014.

Committee Assignment: University, School, and Departmental Committees

CREOL

1. Screening and Recruiting Committee (1998-2000)
2. Industrial Affiliates Committee (1996-1999, 2004-2007)
3. Academic Affairs Committee (1995-1998)
4. Distinguished Visiting Scholars Committee (1999-2007)
5. Student Recruiting Committee (1999-2001)
6. CREOL Industrial Affiliates Day Organizing Committee Member (2004-2007)
7. CREOL University Committee on Emeritus Professorships (2005-2007)
8. CREOL Research Council (2007-2009)

University College Cork, Ireland

1. Head (Dean) of the School of Engineering, June 2013-Sept.2016. Responsible for 800 students and 100 staff.
2. Department Head, August 2011-May 2013.
3. Chair, Physics Lecturer Selection and Appointment Committee, 2012.
4. Member, UCC Tyndall National Institute CEO Selection and Appointment Committee, 2012.

5. Member, UCC Chair Professor in Civil Engineering Selection and Appointment Committee, 2013.

6. Member, UCC Chair Professor in Energy Engineering Selection and Appointment Committee, 2013 and 2016.

7. Chair, UCC Lecturer in Zoology Selection and Appointment Committee, 2014.

8. Member, UCC Chair Professor in Geology Selection and Appointment Committee, 2014.

9. Member, UCC Lecturer in Civil Engineering Selection and Appointment Committee, 2014 and 2015.

10. Member, UCC Lecturer in Electrical Engineering Selection and Appointment Committee, 2014.

11. Member, UCC Chair Professor in Process and Chemical Engineering Selection and Appointment Committee, 2016.

Professional Conferences Service

1. Committee Member, SPIE Conference on Algorithms, Devices, and Systems for Optical Information Processing, San Diego, 1998 to 2009.
2. Committee Member "Electro-Optic Systems & Sensors," IEEE LEOS Annual Meetings,1997, 1998, 1999, 2000, 2001.
3. Session Chair, IEEE LEOS Annual Meetings, 1995, 1996, 1997, 1998, 1999, 2000.
4. Reviewer for the Journals: Optical Engineering, Optics Communications, Optics Letters, Applied Optics, Journal of Lightwave Tech., IEEE Photonic. Tech. Letters
5. Guest Editor, SPIE Working Group Newsletter, April 1999 and Fall 2001.
6. Co-Chair, SPIE Conf. Adv. in Optical Information Processing, Orlando, April 1996
7. Committee Member, SPIE Conference on Adv. in Optical Information Processing, Orlando, April 1998 and 2000
8. Committee Member & Session Chair, SPIE Conferences on Optical Tech. Microwave Appl., 1995 & 1997
9. Committee Member, SPIE Conference on Emerging Optoelectronic Technologies, Bangalore, India, Dec. 1990.
10. Chair, SPIE Special Panel on " Optical Technologies for Wireless Communications," SPIE Annual Meeting, August 2001.
11. Chairman, IEEE LEOS Special Symposium Agile Optical Beams, Glasgow, 2002.
12. Vice President, Membership Americas, IEEE LEOS, Nov. 2002-to-2005
13. OSA Optics in the South East Student Awards Committee, Georgia Tech, Oct. 2005.
14. CoChair, SPIE Conference on Photonic Applications for Aerospace, Transportation, and Harsh Environment II, SPIE Defense, Security, and Sensing Conf. April 2011.
15. Committee Member, SPIE Conf. .Photonic Appl. for Aerospace, Transportation, and Harsh Environment II, SPIE Defense, Security, and Sensing Conf. Baltimore, 2012.
16. International Committee Member, International Conference on Photonics Solutions (ICPS), May 2013, Thailand.

17. Co-Editor, OSA Applied Optics J. Special Issue: Optics in Ireland, August 2018.
18. 2022 ICO International Congress Dresden, Germany Member Technical Program Committee Member and Co-Chair Optical MEMS & Micro-Optics Committee.

External Service as an Invited Scientific Expert for:

1. USA National Science Foundation 1996, 2009.
2. USA National Institute of Standards & Technology (NIST) 1998.
3. USA OIDA (Optoelectronics Industry Development Association) 1997.
4. USA Office of Naval Research (ONR) 1994.
5. USA DARPA 1999, 2000, 2007.
6. Government of Netherlands NRO Panel on Top Research NRC Institutes, 2003.
7. USA Dept. of Energy (DOE) 2006, 2007.
8. USA National Institute of Health (NIH) 2002.
9. Swedish Research and Technology Council 2008.
10. European Research Council (ERC) Review Panel 2014.
11. Royal Irish Academy (RIA) Review Panel 2019.
12. UK Royal Academy of Engineering Industrial Fellowships Selection Panel 2023-24.

Industry Related Activities:

- **Founder, Nuonics, Inc**. a 1998 Start-up Company
  Specializing in Photonic Products for Optical Fiber Telecommunications. Successful commercialization of optical MEMS products using TI DMD DLP technology invented by Riza with tech-transfer & technology sale.
- **Co-Founder, Nusensors, Inc**., a 2005 Start-up Company
  Specializing in Energy Sensors Systems. Successful world record demonstration of extreme temperature gas temperature sensing SiC hybrid optical technology with commecial Siemens Test Rig Engine.
- GE Corporate R & D Center Ph.D Level Recruiter 1990-94 at the California Institute of Technology (doubled Caltech Alumni at GE).
- Have had a Teaming Relationship with Lockheed-Martin Govt. Electronic Systems (LM-GES) on US Sponsored 3-year (1995-1998) radar project.
- Photonic Systems Inc (PSI), Melbourne, FL proto-typed a two channel acousto-optic radar receiver under a US 1995 SBIR Phase 2 program. PSI named this system the “Riza Correlator,” as originally invented by N. A. Riza. This is a case of successful technology transfer from a R & D lab. to a commercial end-user. US Air Force Rome Labs (NY) also further advanced the military use deployment of the Riza wideband RF acousto-optic correlator signal processor.
- Successfully won and completed a Joint SBIR Phase 1 1996 US Program with Photonic Systems Inc., Melbourne, FL, on the 2-D Acousto-optic Inverse Synthetic Aperture Radar Image Processor invented by N. A. Riza.
- On sale of GE Aerospace to Lockheed-Martin in 1995, successful acquistion by Lockheed-Martin (LM) of N. A. Riza optics-based RF signal processing & controls patents for LM aerospace/radar businesses.

Outreach & University Based Extracurricular Activities:

1. Speaker at Local High Schools in Cork Ireland – Presenting his Talk: “ Why study Engineering in College.” The presentation as of December 2021 has 7677 worldwide downloads from the Riza web site.
2. Conducted Photonic Information Processing Lab. Tours for visiting local school students and guests from various conferences such as SPIE Aero-Sense and IEEE LEOS meetings held in Orlando.
3. Using the LEOS student projects such as the mobile setup of CD music transmission through optical communications, highlighted fun in optics at various local and CREOL fairs and Expos.
4. Hosted Local High School Students Ben Katz (Winter Park High School) and Chris Bock (University High School; later BS Stevens Institute of Tech., NJ) in PIPS Lab. as a student assistant.
5. President Caltech International Student Association 1987-89. Started in 1988 the First Caltech International Fair Day for Caltech/JPL Community that has stayed a yearly event for the last 34 years.
6. Captain, Caltech KAOS Soccer Team 1987-89.
7. President, International Student Association, Illinois Inst. of Technology, 1983-84.

Research Impact Areas – A Narrative:

Aerospace and Defense

Riza's Defense Optics activities started from his Caltech Ph.D. student days in the mid-80's where he showed for the first time how Acousto-Optics could be used to control transmit and receive mode RF phased array radars/antennas (Applied Optics 1991) including simultaneous multiple beamforming implementing RF spatial beam multiplexing (IEEE PTL 1992). Later work by Riza at General Electric revolved around developing next generation highest phase stability acousto-optic (AO) RF signal processors such as convolvers, correlators, and spectrum analyzers for wide instantaneous bandwidth Electronic Warfare (EW) applications (Applied Optics 1992, 1994; IEEE PTL 1995). Additional AO signal processing innovations included powerful Range-Doppler (SPIE 1998) and Nulling filter (SPIE 1994, 1996) optical implementations suited for extreme RF bandwidth and signal complexity radar signal processing. **Later, these acousto-optic wide RF signal processor Riza inventions underwent commercial prototyping and military testbed tech transfers at US Air Force Rome Labs and Photonics Systems, Inc., Melbourne, Florida.** In 1992, Riza also invented a 2-D Spatial Light Modulator (SLM)-based powerful high tap and weight count time-delay-based transversal Radio Frequency (RF) filter (US Patent 5329118). In 1995 for tech transfer & commercialization, Lockheed Martin acquired Riza's GE patents on radar controls. In 1999, Riza wrote the Chapter on AO signal processing for RF signals in the Wiley Encyclopedia of Electrical & Electronics Engineering. In 2004, Riza introduced a compact polarization independent version of his original RF filter (Applied Optics).

Another aspect of the Riza group innovations while at GE and later in academia includes a series of pioneering photonic beamforming control systems for Phased Array Radars and Antennas for both narrowband and wideband operations. These innovations formed the most diverse designs for RF beamformer proposed as they engaged a diverse tool set of device technologies including phase control liquid crystals (LCs), polarization rotation LCs, polarization sensitive LC gratings, optical MEMS, AOs, liquid lens, fibers, fiber gratings, wavelength tunable and broadband sources, wavelength tunable filters including multi-wavelength selection, wavelength division multiplexers and solid-optics (in IEEE, OSA, SPIE, Elsevier Publications & US Patents). These works also included the first high speed designs and improvements to realize multiple simultaneous phased array antenna beams in space (IEEE 1992, SPIE &1EEE 2003). In 1997, Riza edited the most comprehensive book in the field of Photonics for Antenna/Radar Controls (SPIE Press). In 2001, Riza invented the most flexible photonic beamformer interface for phased array antennas using LC on silicon SLM device (IEEE 2001, Elsevier 2003). In 2004, **Riza invented new Hybrid Photonic Signal Processing technique that for the first time combines the worlds of analog and digital photonic signal processing leading to world record numbers** of 16 bits RF time delay controls with both long time delays and at high time resolutions (IEEE JLT). In 2009, Riza proposed the first silicon photonics wideband RF phased array antenna beamformer design (SPIE 2010) and a decade later, this subject continues to be a hot topic of research.

In 2002, Riza also pioneered a novel hybrid optical-RF phased array antenna control system that used the same optical hardware to both control an RF array antenna and a steered freespace optical beam (US SBIR 2002). Riza is also a pioneer in the use of optics for security systems as in 1994 (IEEE 1995, SPIE 1996), he pioneered the first optical security systems using multi-dimensional optical ID cards including use of interferometric sensing and RF coded card ID generation.

Health and Imaging

Riza's interest in optics for health and imaging goes back to his 1989 General Electric (GE) days with the development of the ***simplest control liquid crystal variable focus electronic lens*** (Opt. Lett. 1994) motivated by vision applications. In 1995, Riza's group introduced the use of optics for phased array ultrasound controls including the concept of intracavity imaging using optical wavelength-to-image space mapping using a single optical fiber probe and wavelength coding of the spatial array space. Since 1995, the group has also proposed several world first novel optical imaging systems such as in 2001 with the first Digital Micromirror Device (DMD)-based ***agile pixel imager*** using a point photo-detector (2002 Applied Optics) (often called single pixel imager), in 2002 with the first acousto-optics-based Optical Coherence Tomography (OCT) system (Applied Optics 2003), and in 1999 with a ***first wavelength coded optical imager with transmit/receive (T/R) optical amplification and agile wavelength switching & gain controls with tunable or broadband light sources for wavelength-to-space 1-D, 2-D and 3-D W-MOS*** (Wavelength Multiplexed Optical Scanner or ***spectrally encoded imager***) sensing, as well as optical energy delivery for ablation, cutting/surgery (IEEE 1999). The WMOS imager was also extended by Riza to the Interferometric WMOS or I-WMOS phase sensitive spectral sensor imager design for higher sensitivity imaging including depth measurement via reference arm time delay controls (SPIE 2000, IEEE 2002). ***The core Riza lab wavelength encoded optical imaging techniques including for fiber-based endoscopy have been independently used and extended by others*** such as ***Harvard University*** medical labs for numerous medical imaging applications and the ***UCLA*** labs using optical wavelength to time sequential mapping via fiber dispersion (also called time stretch) to form the STEAM ultrafast imager (AIP 2008) for biomedical sensing.

Other pioneering works include Agile Ultrasound Modulated Optical Tomography Techniques using Smart Fiber-Optics (SPIE 2004), Angstrom sensitivity high speed scanning interferometric imagers (AIP 1996), fiber-based scanning imaging endoscopes (SPIE 2000), confocal programmable spectral microscopes (AIP 2005), and world first Electronically controlled Variable Focal Length Lens (ECVFL) or E-lens based agile no-moving parts microscopes (SPIE 2004), endoscopes (OSA 2002) and human vision testers (GE 1990). A more recent world first is the invention of the Optical Array Device based agile pixel full spectrum (UV-SWIR) imager (e.g., using the DMD and/or LED array) to form the Active-Passive mode Coded Access Optical Sensor **(*CAOS*) camera** for extreme linear dynamic range smart imaging (JEOS 2015). ***The CAOS camera set a world record of 177 dB linear dynamic range*** (IEEE 2019) and is uniquely ***designed on the principles of time-frequency RF coding deployed in multi-access RF wireless phone networks***. Such a design inherent provides extreme noise suppression and linearity via RF coding and frequency (Hz) domain filtering (e.g., via DSP methods). One CAOS design features a triple coding feature (Applied Optics 2021) use space-frequency-code manipulations giving a world first extreme embedded security camera. The smart CAOS camera features the hybrid CAOS-CMOS/CCD/FPA mode delivering a novel Pixels of Interest (POI) extreme linear dynamic range camera that combines the best features of CAOS with classic CMOS/CCD/FPA multi-pixel sensors (OSA 2016). Calibrated white light color imaging comparing the CAOS and CMOS cameras has also been conducted proposing how the CAOS camera can overcome the limitations of a CMOS camera when viewing a high linear dynamic range color image (MDPI 2021). The Riza lab in 2019 also pioneered a novel calibration-based minimalistic multi-exposure digital sensor camera robust linear high dynamic range enhancement technique that can be applied to all classic CMOS/CCD/FPA multi-pixel cameras (IS&T & Elsevier 2021).

Communications

Riza and his group's contributions in the field of communications include pioneering works in **RF wireless communications**, **optical wireless communications** and **fiber-optic communications**.

Riza is a pioneer in the use of MEMS for fiber-optic switching (SPIE 1992, US Patent 1993). In the fiber-optic signal attenuation arena, the group has pioneered the most diverse set of variable optical attenuator (VOA) modules using optical MEMS, Acousto-Optic (AO), liquid and Liquid Crystal (LC) technologies (IEEE 1998). ***Riza invented the fault-tolerant all-digital paradigm for designing fiber-optic signal power conditioning modules*** include multi-wavelength equalizer modules (OSA 1999). This technique provides 100% repeatable and energy efficient controls for light flow controls in fiber communications. Riza pioneered the design of fiber-optic signal conditioning and routing modules using the reliable Texas Instruments (TI) Digital Light Processing (DLP) technology, namely using the Digital Micromirror Device (DMD). The group for example proposed and demonstrated using the DMD, the world's first fault-tolerant variable attenuators, all-digital fiber-optic switches, spectral equalizers, tunable laser designs and wavelength sensitive add-drop filters. Riza also invented the Hybrid MEMS/LC design for fiber-optic applications including the hybrid analog-digital design for producing world record performance VOAs (IEEE 2005). Other Riza inventions include super low noise LC switches and low loss MEMS, LC, and hybrid MEMS-LC 3-D cross-connect switches. Specifically, Riza invented the world's first N x N large port count crossconnect design using 3-D beamforming optics that allowed inherent light power attenuation control at localized fiber ports and also provided exceptionally low loss fiber-to-freespace-to-fiber connection designs (US Patent 2000, SPIE 2003, OSA 1999, 2003). ***These methods have been deployed and extended in commercially deployed large crossconnect optical circuit switches*** (e.g., Calient Technologies) ***in data centers around the world***. Many of the Riza's fiber-optical design inventions underwent prototyping and commercialization at **Nuonics, Inc**., a 1998 startup company founded by Riza. The Nuonics design technology underwent acquisition and sale to a global commercial corporation. ***This Riza invented DMD-based design technology and its extension is deployed in many commercialized products*** (e.g., Newport Corp., Cidra Corp., Nistica Corp/NTT Electronics/Fujikura/Molex) ***such as fiber-optic multiwavelength equalizers and routers used across the world fiber-optic communications and internet infrastructure***.

In 1992, Riza & his GE colleagues ***pioneered spatial optical CDMA***, a space division multiplexing (space MUX) method to transmit multiple simultaneous data channels, both for optical wireless and multi-fiber bundle optical data communications (SPIE 1992). The method combined space-time coding to realize a multiaccess optical network. A decade later, many efforts evolved around the world to deploy Space Mux in few mode fiber and multicore fiber to increase data carrying capacity of fiber networks. Realizing that coupling freespace interconnected light between single mode fibers (SMFs) can be a challenge, Riza in 1994 proposed the first use of a variable focus lens for SMF fed optical wireless short range interconnects (IoP 1994) and later extended the work to incorporate 3-D beamforming for robust SMF-freespace-to-SMF coupling controls (SPIE 1997).

Continuing with the same theme of SMF-freespace coupling, the group also developed the most advanced theoretical models for freespace-to-SMF lens coupling (OSA 1999, OSA 2003) that has realized ***near zero loss SMF-to-freespace-to-SMF optical power transfer*** for short distances as well as for longer range optical wireless link distances (Elsevier 2006), including the use of smart optical 3-D beamforming combining cascaded strong and weak lensing via the self-imaging mechanism to form ultra-low loss point-to-point optical datacom links as well as for low loss optical wireless power transfer (IEEE 2012, US Patent Appl. 2014). ***These smart 3-D beamforming works*** have been incorporated around the world to maximize received link optical power for adequate signal-to-noise (SNR) ***to set optical wireless data transmission records*** for terrestrial, indoor and underwater links as well as ***highly efficient optical wireless power transfer links***. In addition, ***designers have used the Riza lab SMF-freespace ultra-low loss coupling models and techniques to commercially deploy millions of SMF-freespace/solid optic-based components that are deployed across the world optical communications and internet infrastructure***.

Riza introduced and demonstrated the first smart indoor multiple beams optical wireless concept (IEEE 1999) **using agile 3-D optical beamforming-based reconfigurable light** (for both laser and LED light) to produce both Line of Sight (LOS) and Non Line of Sight (NLOS) (SPIE 2013) robust and high efficiency indoor optical wireless communications, including its first application for data centers (JEOS 2011, IEEE 2012). Others around the world have used the Riza multibeam reconfigurable indoor optical wireless system to set world indoor optical wireless data records for eye safe telecom C-band operations and develop systems for Industry 4.0 Standard.

Riza introduced the World first inter-satellite optical multi-beams wireless networked system design with on-board optical switching and processing capabilities for space communications to deliver a switchboard in the sky for high data rates globally distributed links & data access (IEEE LEOS Annual Meeting paper 1998). The European Space Agency (ESA) (IEEE 1999), MIT (IEEE 2003) later proposed such concepts & currently Starlink is an example of a deployed & working system.

In the free-space optical wireless domain, ***Riza invented Multiplexed Optical Scanner Technology (MOST)***, a new powerful method using polarization (P-MOS), space (S-MOS), wavelength (W-MOS), and code (C-MOS) multiplexing, including hybrid mux-methods to realize no-moving parts three dimensional steering of light for optical wireless and imaging applications (IEEE 1999). These optical scanners set world records for large aperture 4-pi steradian coverage inertia less optical scanning (OSA 2004). ***Riza also invented the first de-centered liquid lens-based optical beam steering method*** and combined it with liquid lens focus/defocus methods to make smart search and lock-in low loss optical wireless data links (JEOS 2011) as well as fiber-optic attenuation and switching components (Elsevier 2000, 2009, 2009). In 2018, Riza introduced his ***newest invention, the camceiver, the world's first combined camera plus data transceiver module*** with applications in data centers and indoor user ID tag locating systems (IEEE 2018). The camceiver features full spectrum UV to SWIR operations including designs for T/R operations with high speed fiber-optic data links.

Riza is also a pioneer in multiple simultaneous RF beams optical beamforming systems for RF wireless communications phased array antennas and his 1989 Caltech Ph.D. work proposed such smart beamforming systems. In particular, in 1995, ***he was the first to propose the use of optical multi-beamforming systems for RF wireless Base-Station antennas for cellular systems*** including for mm-wave (today called **5G and 6G**) high data rate wireless phased array antennas on a variety of fixed and mobile platforms including automobiles (SPIE 1995). ***He proposed the first design for frequency reuse and smart frequency allocations*** within a cell using spatially multiplexed antenna beams via a multi-beams optical beamformer. ***In addition, in the same 1995 SPIE paper to improve multi-user wireless data transfer performance, he proposed the first design combining the use of carrier/sub-carrier frequency multiplexing and spatial multiplexing*** of multiple simultaneous beams for RF cellular base-station phased array antennas (PAA). This approach was much like the 1996 proposed Orthogonal Frequency Division Multiplexing-Multiple Input Multiple Output (OFDM-MIMO) or spatial-spectral multiplexing MIMO PAA method that today is an IEEE standard for RF wireless communications. Several world labs have pursued both the combined frequency-space Multiplexing multi-beam PAA idea as well use of optical controls approach for mm-wave wireless communication array antennas.

In addition, in the same paper in 1995 (SPIE 1995), he extended the mm-wave RF multibeam multi-user beamforming approach for the optical wireless application creating the first use of multiple simultaneous beams for multiple users using passive as well as electronically programmable beamforming optics such as liquid crystal optical devices. *Effectively,* ***he pioneered Spatial Multiplexing via Optical Multi-beamforming and Spatial-Frequency Multiplexing for both the RF mm-wave and optical wireless domains of multi-access communications***.

Extreme Environment Systems

Generation and control of clean energy such as via combined cycle gas-fired power plants is an important research area for greener economies. Such power plants operate in extreme and hazardous environments and require operations at the newer higher temperatures ranges for better efficiencies and cleaner operations. Riza and co-workers have demonstrated novel extreme environment optical sensors needed for these extreme temperature (> 1500 deg-C) Zero Emissions fossil fuel-based power generation systems. These Riza group inventions include Silicon Carbide-based extreme temperature hybrid design sensors to measure temperature and pressure. To design these Silicon Carbide (SiC) optical sensors, Riza lab conducted the ***first single crystal SiC thermo-optic coefficient material characterization*** and experimental measurements exceeding 1000 deg-C (AIP 2005). Riza and co-researchers ***invented a world first SiC pyrometry-laser interferometry hybrid freespace-fiber-optic design extreme temperature sensor*** for direct measurement of gas temperature in a combustor (IEEE 2006). Temperature sensing experiments using this silicon carbide thermometer placed in a commercial rig reached **world record high temperatures of 1600 deg-C** (ASME 2010). The Riza lab also conducted the first experiments using a SiC optical sensor to measure cryogenic (< 100 K) temperatures (IEEE 2006). Riza also invented the first extreme > 1500 deg-C temperature SiC pressure (> 600 psi) sensors that used 3-D beam spoiling of the SiC sensor structure with laser targeted remote reading and electronic image processing to take gas pressure measurements (Opt. Engg. J. 2007, IEEE PTL 2007).

The Riza group has also proposed and developed the ***world first variable focus lens (or E-lens) based non-contact highest transverse spatial resolution 3-D shape sensors based on spatial processing*** to measure shapes of 3-D objects in extreme environments (OSA 2009). The work included using these sensors for caustic liquid level sensing [Elsevier 2010] as well as active depth from defocus sensing (Elsevier 2015) and the earliest works in distance sensing using machine learning (Elsevier 2017). Riza also pioneered the use of variable focus lens-based low loss optical power transfer optical wireless links using LEDs and lasers (IEEE 2012, US Patent Appl. 2014).

In the late 1980s while doing his Caltech Ph.D. research, ***Riza invented*** an electronically controlled, self-aligning, vibrations robust, ***low noise free-space laser beams Acousto-Optic (AO) architecture using double Bragg diffraction***. This design innovation allowed precision amplitude, frequency, and phase control of laser beams, including Riza lab's ***world record Angstrom scale sensitivity scanning heterodyne laser interferometry demonstration*** (OSA 2003). A unique feature of the architecture is that despite Radio Frequency (RF) steered beam motion, the final AO modulated output beam is stationary allowing coupling to a fixed optical fibre or point detector (AIP 1996, 2005). Thus, a noise immune robust laser beam amplitude/frequency/phase modulation architecture is realized that can operate with many types of lasers with different power levels and spectral characteristics, including infrared band and with laser frequency shifting and RF generation from MHz to several GHz. ***Many worldwide national metrology labs*** (e.g., France's *Laboratoire Commun de Metrologie* LNE-CNAM and USA's NIST) ***have adopted this robust programmable AO architecture to set records in measurement science*** (e.g., 1 picometer wavelength stability 650 nm to 1000 nm spectroradiometer for extreme precision temperature metrology done by French lab, AIP 2016) as well as design precision instruments for absorption spectroscopy, ion spectroscopy, laser cooling and atom clocks.

Another world first is the agile pixel imager including the Coded Access Optical Sensor (CAOS) camera for extreme linear dynamic range as well as bright light smart imaging. See Health and Imaging section for relevant light irradiance measurement instrumentation inventions.

Research Firsts: Example Pioneering Contributions

(Per US Patent Office DataBase, Over 1000 Patents have Cited Riza's works)

Nabeel A. Riza is responsible for the invention of several exceptional performance optics and photonics-based devices, modules, and systems. Examples from the Riza lab are listed next.

1. ***Invention of the All digital paradigm for optical power control in fiber-optic systems*** (US Patent 2001, Optics Letters 1999, Optics Express 2003) where not only is the optical module control via simple digital electronics means but the optical hardware itself is also two state or digital. This innovation has lead the way to replacing today's limited performance all-analog gain control fiber-optics to hysteresis free all-digital highly scalable and robust digital power control fiber-optics. Riza has demonstrated these fiber-optic attenuators using micromirror and liquid crystal (LC) technologies. This is also the first time that the spatial nature of light in terms of its position and interaction area has been exploited in single-mode fiber-optics to realize truly intelligent and simple fiber-optic components. ***Elaborating further, these works include Invention of World first*** digitally controlled fault-tolerant alignment robust fiber-optic switches, tunable lasers, wavelength routing add-drop filter, wavelength all-digital equalizer and variable optical delay lines using small tilt micromirrors (via DMD) based on optical microelectromechanical systems (MEMS) technology (US Patent 2001, Applied Optics 1998 & 2000, Opt Lett. 1999, Opt. Comm. 1999 & 2000, Opt. Engg. 2000), Opt. Exp. 2003). All these modules feature the 100% digitally reliable, repeatable, and energy efficient control of the optical beam states being processed within these fiber connected modules.

Various DMD/DLP based fiber-optic modules from this digital (DLP) module family such as all-digital wavelength equalizer have been commercialized and deployed in the Global Internet. Specifically, these innovations have first successfully undergone product development at Riza's start-up Company ***Nuonics***, Inc. and independent commercialization (see example images & links) at Cidra Corporation and Newport Corporation (https://www.fiberopticsonline.com/doc/new-lambda-commander-lc9500-programmable-spec-0001) Cidra sold it as an equalizer for optical networks and Newport offers it as a test instrument for processing broadband light. In addition, Nistica Corp/NTT Electronics Japan, later bought by Fujikura Japan & now owned by Molex, USA (https://www.molex.com/molex/products/group/passive_components) has commerialized this DMD-based fiber-optical modules technology as its FULL-FLEDGED (now Bernoulli) product series including DMD DLP based equalizers and routers/switches, now deployed in fiber-optic networks around the world. (https://www.businesswire.com/news/home/20180312005164/en/Nistica-Launches-Wavelength-Management-Products-for-Data-Center-and-5G-Mobility-Applications).

2. ***Invention of Multiplexed Optical Scanner Technology*** or MOST (IEEE 1999, US Patent 2004) that ***exploits multiplexing of polarization, wavelength, space and optical spatial codes*** to realize powerful multidimensional scans for various applications that includes imaging, fiber-based endoscopy, light power delivery, data optical wireless communications and data reading. For example, the ***polarization MOS*** or P-MOS is a digitally controlled, no moving parts, low (mW) control power, LC-based structure for fast microsecond speed three dimensional scanning of a light beam where birefringent static lenses and x- and y- prisms are placed sequentially along the beam and are dynamically activated or deactivated by digital control of polarization switches. ***The Riza lab set a world record for the fastest large aperture 3-D optical scanner which includes demonstrating the fastest variable focus large aperture*** (e.g., 1 cm diameter) ***lens*** (Optics Lett. 2003 & Optics Express 2004). The ***wavelength MOS*** or W-MOS (IEEE 1998, Applied Optics 2001) exploits the exceptionally fast (e.g., nanosecs) wavelength tuning ability of modern lasers or wavelength selection with broadband light, including optical amplification for generating light to engage passive dispersive optics (e.g., Volume and planar Grating Optics) to realize a large beam active area superfast speed scanner. W-MOS can also engage 3-D distributed fiber optics to cover very large scan ranges or fiber-optics to form ultracompact endoscopes. The core Riza lab ***wavelength encoded optical imaging techniques*** have been independently used by the ***UCLA*** labs using optical wavelength to time sequential mapping via fiber dispersion (also called time stretch) to form the STEAM ultrafast imager (AIP 2008) for biomedical sensing.

3. ***Invention of the Space MOS*** or S-MOS in the MOST family that uses optical switched fiber-optic bundle with lens optics to make a spatially multiplexed optical scanner (Applied Optics 2004). Hybrid optical designs were also invented such as W-MOS with S-MOS (SPIE 2001) in addition to ***inventing hybrid analog-digital devices control of the optical scanners*** to provide both fine and coarse beam scan controls (Optics Lett. 2003) . The Code MOS or C-MOS or ***spatial CDMA*** scanner (Applied Optics 2004) uses holography with input beam activation spatial codes to produce a simple no-movings parts 3-D scanner with ***world record extreme 4pi-steradian range beamforming capabilities*** (Optics Lett. 2004) with extremely wide angle coverage (e.g., 360 degrees) and large apertures (e.g., 1 cm). All MOSs are unique pixelation-free devices with large clear apertures, a great asset for optical scanners.

4. ***Invention of the interferometric W-MOS or interferometric spectrally encoder 3-D mapping imager (SPIE 2000, IEEE 2002, Agile High Sensitivity Optical Sensor, US Pat. Appl. 2003)*** that apart from transverse section imaging can also provide axial or depth sectioning to realize 3-D image maps. This sensor design that applies to intracavity of fiber-optic endoscopy used both broadband light or tunable light in an interferometric design where the reference arm of the interferometer uses a variable optical phase/time delay to create a depth discrimation method to allow the formation of full 3-D sample image maps. This core ***spectrally encoded image sensing work*** has been independently used and extended by others such as ***Harvard University*** medical labs to demonstrate imaging for numerous successful medical applications including powerful highly sensitive endoscopes.

5. ***Invention of the all-digital agile pixel paradigm (US Patent 2001, 2005) in passive optical imaging*** including for laser beam profiling. For the first time, ***demonstrated a world best 100% digital repeatability spatial profile measurements***, in particular, for high power laser beams is possible via the use of a ***Digital Micromirror Device*** (e.g., TI MEMS DMD) (Applied Optics 2002). Unlike old analog mechanical profiling methods, the new digital method performs real-time measurements in addition to implementing several profiling methods (e.g., slit, knife-edge, pinhole, etc.) via software programming of the same unit (Applied Optics 2002). Nuonics,Inc developed this DMD-based laser imaging technology for commercialization. The company engineered an economical DMD profiler kit for beta testing and sale using DMD pico-chip technology.

6. ***Invention of a double Bragg diffraction self-aligning acousto-optic (AO) architecture*** (OSA Mtg 1988) ***allowing amplitude, frequency, phase modulation of laser beam via RF control*** at a microsecond/point scanning speed. Demonstrated AO scanning interferometer using the double Bragg diffraction AO architecture measuring optical phase/displacement with ***World record 1 Angstrom optical path length resolution*** (Applied Optics 2003).

7. ***Invention of a world record acousto-optic fiber-optic attenuator*** design (IEEE 2002) that for the first time can simultaneously deliver features such as zero net Doppler, high 50 dB dynamic range (i.e., ***amplitude modulation range***), sub-microsecond switching speed, low < 1.6 dB loss, high 1 Watt laser damage threshold, and low < 0.2 dB polarization dependent loss (PDL). This attenuator uses a unique in-line Doppler-free double acousto-optic Bragg diffraction architecture with polarization geometry flipping induced via a waveplate that leads to a drastic reduction in PDL.

8. ***Invention of a*** liquid crystal (LC) and ***acousto-optic device-based structures*** for ***freespace optical beam switching*** with ***World record*** high (e.g., -50 dB) optical noise rejection (Optics Letters 1994 & 1997). Variable optical delay lines covering 10-13 sec. to 10-6 sec. were invented and realized based on digital control of these switches including ***World first fiber-based variable delay lines*** using polarization switching

that are insensitive to polarization scambling caused by the delay fibers (Optics Lett. 1995; IEEE Micro. Lett. 1997).

9. ***Invention of a liquid crystal (LC) switches*** for fiber-optics that simultaneously demonstrate ***World record*** fastest speeds and lowest crosstalk levels by employing passive and active noise rejection schemes (IET Lett. 1998). These noise reduction methods have been deployed in commercial LC-based products.

10. ***Demonstration of a novel optimized Free-space fiber lens to fiber lens coupling model*** (Applied Optics 1999) that mathematically and experimentally showed the tilt and translational sensitivity involved with designing and building freespace systems deploying input/output fiber lens-based fiber-optics. ***This model is now used in industry to optimize freespace-fiber coupling module designs for millions of internet deployed components***.

11. Invention of a freespace coupling-based fiber-optic large optical crossconnect (OXC) switch design that uses 3-D beamforming effect to give controlled beamsteered switching as well as optical power attenuation controls on each fiber port (US Patent 2000, SPIE 1998, 2003). ***This 3-D beamforming approach including the built-in port variable attenuator is now used in major deployed commercial OXCs (e.g., Calient Tech) in internet deployed Data Centers.***

12. ***Invention of a*** a simple yet highly effective ***variable fiber-optic attenuator*** that takes delibrate advantage of a nasty ***3-D beam spoiling*** effect to give controlled optical power attenuation (Applied Opt. 1999, Opt. Comm 2000, Opt. Engg. J. 2004). Here, a negative aspect of physical optics was turned into a positive aspect for fiber-optic component design.

13. ***Invention of a*** self-imaging technique for fiber-lens to fiber-lens interconnections and advanced coupling model via freespace and solid-optic gaps using less than quarter-pitch design fiber lens that leads to an exceptionally low loss coupling with a ***World record near zero fiber-to-freespace-fiber coupling loss*** (Applied Optics 2003). Specifically, the Gaussian beam over a given freespace distance experiences a converging and diverging effect that is equivalent to self-imaging. This effect and self-imaging method is commercialized and used by industry (e.g., LightPath fiber collimators). ***This method and advanced coupling model is now used in industry to minimize loss in freespace-fiber coupling module designs for millions of internet deployed components plus in large over 300 x 300 port OXC designs that are also currently deployed in Data Centers in the internet***.

14. ***Invention of*** coherent high phase stability and low control power method **for *optically generating frequency, amplitude, and phase-controllable optical and microwave radar signals*** using in-line double Bragg diffraction acousto-optic modulation of two polarization encoded optical waves illuminating an array of LC pixels (OSA Mtg. 1998, SPIE 1991, Applied Optics 1991 and 1994, AIP RSI 1996).

This ***double AO Bragg diffraction optical modulation architecture*** has been deployed by Metrology Labs around the world (e.g., LNE-CNAM-France, NIST-USA, Beijing-China, *División de Tiempo y Frecuencia, Centro Nacional de Metrología* Mexico) to set ***world records in measurement science***, including for absorption spectroscopy, ion spectroscopy, laser cooling and atom clocks.

15. ***Invention of*** coherent and robust ***acousto-optic processor*** for RF spectrum analysis, correlation, and convolution delivering high (>70dB) dynamic range processing of extremely wide instantaneous bandwidth (>500MHz) RF signals (Applied Optics 1992 & 1994, IEEE PTL 1995). ***These wideband radar signal processors where commercialized and developed by both industry (e.g., Photonic Systems Inc. Melbourne, FL) as well as US Air Force Rome Labs, NY***.

16. ***Invention of World first Multiple Beamforming Optical System for mm-wave 5G/6G RF wireless base station*** Phased Array Antennas (SPIE 1995). Two decades later, world researchers are pursuing this theme for next-gen RF wireless systems. In the same 1995 SPIE Proceedings paper, Riza extended his mm-wave RF multibeam multi-user beamforming approach to the optical wireless application, ***creating the first use of multiple simultaneous beams for multiple users using passive and electronically programmable beamforming optics*** such as liquid crystal phased array optical devices. He effectively **pioneered reconfigurable Spatial Multiplexing via Optical Multi-beamforming for both the RF mm-wave and optical wireless domains of multiple access cellular communications.**

17. ***Invention of*** **LC** ***variable focus lens device*** that incorporates a thin film resistor-network electrode structure on a high impedance amorphous silicon thin film, thus providing near continous optical phase beamforming control via a simple control voltage vs. a multi-voltage computer controller (Opt. Lett. 1994). Numerous world labs have adapted this work to design various electrodes on a high impedance amorphous silicon thin film to make simple to control functional LC lens devices.

18. ***Invention of*** LC lens-based ***optoelectronic eye examination*** system such as for eye lens refractive power measurements for new glasses (1989 GE New Start Award proposal, US Patent Appl. 2003, MDPI Photon. J. 2015).

19. ***Invention of World first*** high speed, no moving parts, ***optical/ultrasonic phased array scanning probe*** using a single fiber cable and multiple wavelengths with passive dispersive optics (e.g., grating) to deliver intracavity access (IEEE 1996, US Patent 1998).

20. ***Invention of*** freespace multiple access optical communication scheme using space-time codes. Also called ***Spatial Optical CDMA, this Spatial Multiplexing data transmission scheme*** works for both multi-fiber (or multicore fiber) links as well as Optical Wireless data links (SPIE 1992, Applied Optics 2002, IEEE JSAC 2005). This invention is the ***world's first use of Spatial MUX for optical wireless***

communicatons and amongest the earliest works in space-Mux for multi-fiber data transmission.

21. ***Invention of the World's first optical security system using the multidimensional optical scanning and RF space-time encoding*** and decoding of ID data including both ID optical phase and amplitude information (IEEE 1995, Opt. Engg. J. 1996).

22. ***Invention of the World's first Hybrid Digital-Analog MEMS Optical Beam Profilers*** for Laser Beam Characterization (US Patent 2006, IEEE PTL 2005). This imager allows direct imaging of laser beams from the UV to SWIR band with micron size precision.

23. ***Invention of the World's first*** Optical power fluctuation independent noise robust ***optical irradiance imager*** design using Digital MEMS Spatial Light Modulator (i.e., DMD) and two point detectors (Opt. Engg. J. 2004). This first-of-a-kind two point detector design engages the symmetric 2-tilt state operation of the digital micromirrors in the DMD, allowing electronic signal processing operations on the two photo-detected signals such as the well known balanced detection method to reduce noise in final recovered image.

24. ***Invention of Agile Pixel Active and Passive*** DMD/LC SLM ***Optical imager*** design for smart imaging (Opt. Comm. 2010). Riza lab's earlier passive light DMD imager design is extended for use with an active light source within the camera structure.

25. ***Invention of Non-Invasive Liquid Crystal Optical Beam Profiler*** for Laser Beam Characterization (Opt. Express 2004). Specifically, input laser beam light strikes a non-pixelated SLM zone providing LC structure limited very high spatial resolution optical irradiance response that is extracted by another pixelated SLM device.

26. ***Invention of*** "***Hybrid Analog-Digital Photonic Signal Processing***", with ***World First Hybrid Analog-Digital Technique Fiber-Optic Variable Delay Line, Fiber-Optic Broadband Spectral Equalizer and Variable Optical Attenuator*** modules that can simultaneously provide the highest resolution over the widest dynamic control range- a feat not possible before for the mentioned component categories. Results for the hybrid Analog-Digital Fiber-Optic Variable Delay Line for RF signals has shown 16-bit ***World Record*** Numbers (IEEE JLT 2004, IEEE PTL 2005, Optics Letters 2008).

27. ***Invention of World first Highest weight and time delay tap programmability RF transversal filter*** using optical MEMS (i.e., DMD) for Microwave/mm-wave signal processing (Applied Optics 2004). Invented one of the earliest RF optical transveral filters (US Patent 1994).

28. ***Invention of World first No-moving parts variable focus lens axial scan microscope*** applicable also for broadband light. ***First demonstration of blood vessel imaging***

using the variable focus lens axial scan microscope (SPIE 2004, Opt. Comm. 2006, Opt. Engg. J. 2008).

29. ***Invention of World first Largest beam profiling aperture*** (15 inch diagonal) no-moving parts LC-based laser beam profiler (Applied Optics 2007).

30. ***Invention of World first Highest measurement range hazardous environment wireless optical sensors*** for ***ultra hot*** (> 1500 deg. C) and ***ultra-cold cryogenic*** (< 100 K) temperature and extreme pressure (> 600 psi) measurements. The sensors used a new all-Silicon Carbide (SiC) hybrid fiber+freespace tunable infrared laser targeted design combining single crystal and sintered SiC. Conducted first over 1000 deg-C thermo-optic coefficient measurements for single crystal SiC (AIP J. App. Phys. Lett. 2005). ***Invented the first extreme temperature sensor combining pyrometry with laser interferometry*** to realize a self-calibrating temperature sensor robust to vibrations. ***Conducted record 1600 deg-C temperature tests in a Siemens Combustion Engine Rig*** facility in Orlando, with successful extreme direct combustion gas temperature measeuements (SPIE OFS17 2005, IEEE 2005 & 2006, IEEE 2010, ASME 2010).

31. ***Invention of World first Highest > 1500 deg-C temperature operational range*** hazardous environment ***wireless optical pressure sensors using SiC*** surface 3-D beamforming with optical spatial processing and electronic image processing for laser beam targeted pressure measurements (Opt. Engg. J. 2007, IEEE PTL 2007).

32. ***Invention of World first Hybrid optical multi-beams wireless system design for indoor communications using agile 3-D optical beamforming*** to deliver high data rates and robustness to blocking energy efficient Light of Sight (LOS) and Non-Line of Sight (NLOS) links (IEEE 1999, Opt. Engg. J. 2013).

33. ***Invention of World first inter-satellite optical multi-beams wireless networked system*** design with onboard optical switching and processing capabilities for space communications to deliver a switchboard in the sky for high data rates globally distributed links & data access (IEEE LEOS Annual Meeting paper 1998). The European Space Agency (ESA) (IEEE 1999), MIT (2003) later proposed such concepts & currently ***Starlink*** is an example of a deployed & working system.

34. ***Invention of World first hybrid optical wireless link design using Variable Focus Electronic Lenses and fixed lens optics*** to deliver for the first time near ***zero propagation loss green links*** using minimal photons loss. The core design is based on use of agile 3-D beamforming to enable low loss high data rate links for indoor data centers, short-to-long range outdoor links, under-water and inter-satellite links as well as remote power transfer optical wireless links. Specific use of the proposed self-imaging effect ***via weak lensing combined with strong lensing*** to realize near zero loss high data rate optical wireless links coupling to single mode fiber-optics and/or small active area opto-electronics (Opt. Comm. 2006, EOS JEOS 2011, IEEE 2012).

35. ***Invention of World first direct laser spot beam spatial processing distance/displacement sensor using variable focus lenses***. Applications demonstrated include ***liquid level sensing and 3-D object reconstruction*** (Opt. Lett. 2009). This system has in 2014 been shown to defeat the classic Rayleigh axial resolution optical diffraction limit – to our knowledge, the first time such a feat has been achieved (Applied Optics 2014). The classic Rayleigh transverse resolution optical diffraction limit was broken earlier by S. Hell and others in the 1990's.

36. ***Invention of World first*** no-moving parts ***variable focus lens based laser beam propagation analyzer***. Design also engaged with the DMD-based laser beam imager for broadband operations (Applied Optics 2010, AIP RSI 2011).

37. ***Invention of World first de-centered variable focus electronically controlled lens freespace laser beamsteering*** with first use of MEMS lens (SPIE Opt. Engg. 2004) and no-moving parts ***variable focus liquid lens*** (Elsevier J. Opt. Comm. 2009) ***based fiber optic variable optical attenuator, switches, and variable optical/RF delay lines***. Designs used both off-centered liquid lenses and on-axis lenses in cascade to deliver these novel fiber-optic component designs (IEEE PTL 2009, Opt. Comm. 2009 and 2010).

38. ***Invention of World first*** no-moving parts ***variable focus lens based Smart laser scanning display*** design that delivers the highest spatial resolution display for any given screen projection distance (IEEE JDT 2011).

39. ***Invention of World first Silicon Photonics-Based Wideband Time Delay Phased Array Antenna/Radar Beamforming Design*** (US Patent Appl. 2009; Opt. Engg. J. 2010).

40. ***Invention of World first Active depth from defocus system using coherent illumination*** and a no moving parts camera that forms a Depth from Defocus Camera for extended range 3-D imaging (Opt. Comm. 2015).

41. ***Invention of World first extreme linear dynamic range full spectrum camera*** designed on the principles of the RF multi-access wireless network. Called the ***CAOS or Coded Access Optical Sensor Camera***, it has both light active and passive modes and hybrid operation modes that provide extreme security imaging. The CAOS camera has a smart camera design that combines CAOS with classical CMOS/CCD/FPA sensors. CAOS has ***demonstrated a world record 177 dB linear dynamic range*** (EOS JEOS J. 2015, Optics Exp. 2016, Applied Optics 2018, IEEE 2019).

42. ***Invention of World first extreme linear dynamic range full spectrum spectrometer*** designed on the principles of the RF multi-access wireless network. Called the ***CAOS***

or Coded Access Optical Sensor Spectrometer, it has both 1-D and 2-D scan modes (SPIE 2016, IEEE PTL 2020).

43. ***Invention of World first Optical Camera plus Wireless Data Transceiver Unit***, called ***Camceiver*** and proposed its first use in indoor Data Centers and User Positioning System Applications (IEEE 2018 & 2019).

44. ***Invention of World first Calibration Centric Extreme Linearity Robust Minimal Images Multi-Exposure High Dynamic Range Image Recovery Technique*** for All Multi-pixel Sensor Electronic Vision Systems (IS&T 2020, Opt. Comm. 2021).

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[4-24] N. A. Riza, "Recent experimental results from the GE-CRD optical controllers for phased array antennas: Part 2 - L-band Demonstration of the Phase-only Optical Beamformer," *General Electric Technical Publication Series*, 94CRD051-Part 1, April 1994.

[4-25] N. A. Riza and M. C. DeJule, "Novel Programmable Nematic Liquid Crystal Lens Devices," *General Electric Technical Publication Series, 9*4CRD076, May 1994.

[4-26] N. A. Riza, "Space Integrating Coherent Optical Convolution System," *General Electric Technical Publication Series*, 94CRD120, July 1994.

[4-27] N. A. Riza, "Liquid crystal optical transversal filter," *General Electric Technical Publication Series*, 94CRD176, Sept., 1994.

[4-28] N. A. Riza, "Optical technique using magnetostatic wave deflectors for controlling phased array antennas," *General Electric Technical Publication Series*, 94CRD175, Sept., 1994.

[4-29] N. A. Riza,"Optical technique using electrooptic deflectors for phased array antenna control," *General Electric Technical Publication Series*, 94CRD174, Sept., 1994.

Invited Presentations and Seminars/Colloquia (92):

1. N. A. Riza, Seminar on " Electro-optical control of phased array antennas," at the Rennselaer Polytechnic Institute (RPI), Electrical Engg. Dept., Troy, New York, U.S.A., Oct.17, 1991.

2. N. A. Riza, "Prospects of optical information processing systems - The years 1995 and beyond," at the OIDA (Optoelectronics Industry Development Association) *Optics in Switching & Computing Technology Vision Workshop*, Baltimore, May 7-8, 1993.

3. N. A. Riza, "Optical Signal Processing," Dept. of Electronics, Quaid-e-Azam Univ., 1993.

4. N. A. Riza, " Radar Controls using Light," GIK Institute of Science and Technology, 1994.

5. N. A. Riza, " The Power of Light: Radar Controls,"Aitchison College, 1994.

6. N. A. Riza, "Liquid Crystals and Signal Processing," Dept. of Electronics, Quaid-e-Azam Univ., 1994.

7. N. A. Riza, "Advanced optical techniques for phased array antenna control using liquid crystal display (LCD) technology," in *Workshop Digest on Optoelectronic Technology for Future Navy Active Array Radar*, Sept.8, Crystal City, VA, 1994.

8. N. A. Riza, "Spatial light modulator technology and its application to phased array antennas," Seminar/presentation at the *Naval Surface Warfare Center (NSWC)*, Dahlgren Division, August 17, White Oak, ML, 1994.

9. N. A. Riza, Seminar on " Liquid crystal display technology-based photonic controllers for phased array antennas," at the Yale University, Dept. of Electrical Engineering, New Haven, CT, USA, March, 1994.

10. N. A. Riza, "The Road to Innovation and Advanced Product Development," LUMS Center for Management & Economic Research (CMER) Seminar, LUMS, Jan., 1994.

11. N. A. Riza, Seminar on "Advances in three dimensional photonic control modules for phased array radars," at MIT Lincoln Laboratory, Oct.18, 1996.

12. N. A. Riza, Seminar on " Photonically Controlled Phased Array Antennas--A Research Journey via Caltech, General Electric, and CREOL-Univ. Central Florida,"at Dept. of Electrical and Electronic Engineering, University College London, London, U.K., Jan. 29, 1997.

13. N. A. Riza, Seminar on "3-D Optically Controlled Phased Array Systems," at the Dept. of Engineering, Cambridge University, Cambridge, U.K., Jan. 31, 1997.

14. N. A. Riza, Seminar on "3-D Photonic Systems for Controlling Ultrasonic Phased Array Systems," at the Dept. of Biomedical Engineering, Duke University, Durham, NC., April 18, 1997.

15. N. A. Riza, Seminar on "3-D Photonic Technologies and Methods for Controlling Phased Array Systems," at the Dept. of Electrical Engineering & Computer Science, MIT, Cambridge, MA., April 29, 1997.

16. N. A. Riza, Seminar on "3-D Photonic Systems for Controlling Ultrasonic Phased Array Systems," at the Applied Optics Group, Dept. of Physics, Imperial College of Science, Technology & Medicine, London, U.K., July 14, 1997.

17. N. A. Riza, "Photonic signal processing for phased array sensor systems," IEEE LEOS Annual Meeting, Orlando, FL, Dec., 1998.

18. N. A. Riza, Seminar on " Optics for Switching, Processing, and Controls: The Next Generation Platform for 21st Century Communication Systems," Department of Applied Physics, COBRA Institute, Eindhoven University ofTechnology (TUE), Eindhoven, The Netherlands, June 15, 1998.

19. N. A. Riza, Seminar on "Photonics for Next Generation Telecommunication Systems," Moore School of Electrical Engineering, University of Pennslyvania, Philadelphia, Nov. 1998.

20. N. A. Riza, Seminar on "Photonic Innovations: A High Impact Multidisciplinary Approach for Advanced Sensing, Testing, Computing, and Communication Systems," Northwestern University, Feb., 1999.

21. N. A. Riza, "Optics for wireless technologies," US-Japan Joint Optoelectronics Program (JOP) Workshop, San Francisco, April 1999.

22. N. A. Riza, "Optical Beamforming for laser communications," DARPA ETO Program Workshop on Laser Communications, Virginia, April 1999.

23. N. A. Riza, Seminar on "Telecommunication Controls See the Light," University of California-Sana Cruz, March 14, 2000.

24. N. A. Riza, Invited presentation on "Wavelength Sensitive Photonic Modules for Signal Conditioning," DARPA/MTO WDM for Military Platforms Workshop, McLean, VA, April 18-19, 2000.

25. N. A. Riza, Seminar on "All-Optical Telecommunication Switching using Liquid Crystals ," Department of Electrical Engineering, Technical University of Delft, Delft, The Netherlands, July 3, 2000.

26. N. A. Riza, " Photonic Signal Processing for Antennas," DARPA/MTO Analog Optical Signal Processing (AOSP) Workshop. December 6, 2000. http://www.darpa.mil/mto/aosp/workshop/riza.pdf

27. N. A. Riza, Seminar on " Innovative Fiber Optical Attenuation Control Modules using Moving and No-Moving Parts Photonics," Department of Applied Physics, COBRA Institute, Eindhoven University of Technology (TUE), Eindhoven, The Netherlands, July 11, 2001.

28. N. A. Riza, Seminar on " Towards a World Class Research University in Science and Technology- Money is Critical but Not Enough," Session on Reform at the University Level: Money, Pak-Millennium Conference 2002: Higher Education in Pakistan-Challenges for Reform, Boston University School of Management, April 14, 2002.

29. N. A. Riza, " SMP™ : Spatially Multiplexed Processing Technology for Fiber-Optics," Seminar @ Engineering Department, Cambridge University, Feb.27, 2002

30. N. A. Riza, **"**Paradigm Shifting Fiber Optical Attenuation Technology," Seminar @ Blackett Labs, Imperial College, London, Noon, March 1, 2002.

31. N.A. Riza, " Intelligent Light for Signals," ICO Prize Invited Paper, ICO XIX Conference Digest, SPIE Proc., Florence, Italy Aug. 2002.

32. N. A. Riza, " Multi-Band Multi-Space Optical Probing," The 3rd Inter-Institute NIH Workshop on Diagnositic Optical Imaging & Spectroscopy: The Clinical Adventure , Bethesda, Sept.26-27, 2002.

33. N. A. Riza, " Multiplexed Optical Scanner Technology," EE Dept. and LEOS Lecture Series Seminar, Old Dominion Univ., August 2002.

34. N. A. Riza, “ Agile Scanners for Biomedical Optics,” Univ. of Iowa Medical School, Dec. 2002.

35. N. A. Riza, “ Optical Controls See the Light,” McGill Univ., ECE Dept. Seminar. Feb. 27, Montreal, Canada, 2003.

36. N. A. Riza, “ Sensor Controls via Light,” Stanford Univ., EE and Applied Phys. Dept. Seminar, May 12, 2003.

37. N. A. Riza, “ Free-space Optics and Fiber-Optics for Communications and Controls,” Institute of MicroTechnology (IMT) Seminar, Univ. of Neuchatel, Switzerland, July 18, 2003.

38. N. A. Riza, “Intelligent Communications using Fiber and Freespace Optics,” COBRA Institute, Tech. Univ. Eindhoven, Phys. & EE Dept. Seminar, Netherlands, July 21, 2003.

39. N. A. Riza, “ Multiplexed Optical Scanners and Applications,” Fitzpatrick Center for Optical Communications Fall 2003 Distinguished Seminar Series, Duke University, Oct.21, 2003.

40. N. A. Riza, “Smart Communications & Sensor Controls using Optics,” IEEE LUMS Chapter Seminar, LUMS, Dec.17, 2003.

41. N. A. Riza, “Smart Optical Scanners,” IEEE LEOS Chapter Seminar, Univ. of New Mexico and CHTM, April 27, 2004.

42. N. A. Riza, “Smart Optical Scanners and MEMS,” Seminar, ETH: Swiss Federal Institute of Technology, Zurich, May 13, 2004.

43. N. A. Riza, “ Intelligent Optical Scanners,” Winter College on Optics Seminar, Abdus Salam International Center for Theoretical Physics (ICTP), Trieste, Italy, Feb.11, 2005.

44. N. A. Riza, “ Multi-dimensional Optical Scanners,” EE Dept. Seminar, UCLA, March 14, 2005.

45. N. A. Riza, “ Innovations in Light Scanning,” Seminar, Caltech, EE Dept., March 16, 2005.

46. N. A. Riza, “Scanning is Light Work,” EE Dept. Seminar, Cornell University, April 26, 2005.

47. N. A. Riza, “Space-Time Manipulations of Light Beams,” EE Dept. Seminar, University of Southern California, July 27, 2005.

48. N. A. Riza, Seminar on “ Hybrid Photonic Signal Processing,” Department of Electrical Engineering, COBRA Institute, Eindhoven University of Technology (TUE), Eindhoven, The Netherlands, Sept.2, 2005.

49. N. A. Riza, Invited Tutorial: Liquid Crystal Agile Optics, OSA Optics for Liquid Crystals International Meeting, Oct. 1, 2005, Clearwater, Florida.

50. N. A. Riza, “ Optical Sensors for Space Applications,” European Space Agency (ESA), ESTEC, Optoelectronics Section, 2006, Noordwijk, Netherlands

51. N. A. Riza, Seminar on “Optical Sensor Solutions for 21st Century Global Challenges in Energy,” Institute of MicroTechnology (IMT), Univ. of Neuchatel, Switzerland, July 5, 2007.

52. N. A. Riza, Seminar on “Photonic Sensor Solutions for 21st Century Global Challenges in Energy Production,” Department of Electrical Engineering, COBRA Institute, Eindhoven University of Technology (TUE), Eindhoven, The Netherlands, July 18, 2007.

53. N. A. Riza, Seminar on “Silicon Carbide Hybrid Optical Sensors for Next Generation Greener Gas Turbines,” Department of Mechanical Engineering, Caltech, Pasadena, Nov.13, 2007.

54. N. A. Riza, Seminar on “Silicon Carbide Hybrid Optical Sensors for Next Generation Greener Power Generation Systems,” Illinois Institute of Technology, Chicago, May 1, 2008.

55. N. A. Riza, Seminars on “Advances in Photonic Signal Processing,” Institute of Optics Graduate School, Ecole Poytechnic-Campus Palaiseau, University of Paris-SUD, May 13-15, 2008.

56. N. A. Riza, Seminar on “Advanced Imaging of Laser Beams,” Faculty of Applied Sciences, Dept. of Imaging Science and Technology Seminar, Delft University of Technology, June 30, 2008.

57. N. A. Riza, Seminars on “Advances in Laser Beam Measurement and Wideband Microwave Radar Controls,” Ernst Abbe Center, Friedrich Schiller University of Jena, Germany, July 10, 2008.

58. N. A. Riza, Seminar on “Electronically Agile Confocal Microscopy,” at the Dept. of Physics, Imperial College of Science, Technology & Medicine, London, U.K., July 24, 2009.

59. N. A. Riza, Seminar on “ Extreme Temperature Sensing for Greener Power Plants,” at the Dept. of Physics, National Univ. of Ireland, Galway, July 17, 2009.

60. N. A. Riza, Seminar on “ Extreme Temperature Sensing for Greener Power Plants,” at the Dept. of Electrical & Computer Engg., Lehigh Univ., Sept, 2009.

61. N. A. Riza, Seminar on “ Extreme Temperature Sensing for Greener Power Plants,” at the National Research Council, Ottawa, Canada, Oct, 2009.

62. N. A. Riza, Seminar on “ Extreme Temperature Sensing for Greener Power Plants,” at ECE Dept., Rice Univ., Houston, 2010.

63. N. A. Riza, Seminar on “ Extreme Temperature Sensing for Greener Power Plants,” at the ECE Dept., University of New Mexico, 2010.

64. N. A. Riza, Seminar on “ Extreme Temperature Sensing for Greener Power Plants,” at MIT Lincoln Lab., 2010.

65. N. A. Riza, Seminar on “ Extreme Temperature Sensing for Greener Power Plants,” at the University of Ghent, Belgium, 2010.

66. N. A. Riza, Seminar on “ Extreme Temperature Sensing for Greener Power Plants,” at the Strathclyde University, Scotland, 2010.

67. N. A. Riza, Seminar on “ Extreme Temperature Sensing for Greener Power Plants,” at the City University London, 2010.

68. N. A. Riza, Seminar on "Empowering Next Generation RF & Optical Sensor Systems: Innovations in Hardware & Signal Processing," Department of Electrical & Computer Engineering, The Ohio State University, Columbus, 2010.
69. N. A. Riza, Seminar on "Empowering Next Generation RF & Optical Sensor Systems: Innovations in Hardware & Signal Processing," Photonic Seminar Series, Tyndall National Institute, University College Cork, Ireland, Nov.2, 2011.
70. N. A. Riza, Seminar on "Inventing with Light: A Personal Journey," Seminar Series, LUMS School of Science and Engineering, April 2012.
71. N. A. Riza, Seminar on "Inventing with Light: A Personal Journey," Electrical Engineering Dept. and COBRA Seminar, Technical University of Eindhoven, May 2012.
72. N. A. Riza, Seminar on "Inventing with Light: A Personal Journey," IEEE Student Chapter and EEE Dept. Seminar Series, University College Cork, Oct. 2012.
73. N. A. Riza, Seminar on " Smart Laser Scanning Display," Engineering Department, CAPE Bldg, Cambridge University, July 18, 2013.
74. N. A. Riza, Seminar on " Smart Imagers," Electrical & Electronic Engineering Department, University College Dublin (UCD), Oct.4, 2013.
75. N. A. Riza, Seminar on " Smart Imagers," Hamlyn Center Distinguished Lecture, Imperial College London, Feb., 2014.
76. N. A. Riza, Seminar on " Smart Imagers & Displays," Keynote Address, OSA Chapter Conference, National Univ. of Ireland, Galway, April 4, 2014.
77. N. A. Riza, Seminar on " Smart Imagers," School of Engineering, Trinity College Dublin (TCD), May 2, 2014.
78. N. A. Riza, "Agile Pixel Optical Imaging Technology - A Paradigm Shift towards Smart Imager Design," Invited Distinguished EE Division Lecture at KAUST: King Abdullah University of Science and Technology, KSA. Oct., 2014.
79. N. A. Riza, Seminar on "Agile Pixel Imagers," Faculty of Engineering Distinguished Lecture, Technical University of Dresden, Germany, 2014.
80. N. A. Riza, "Smart Photonic Sensors Performing for the Environment," Invited Speaker at the 10 Year Celebrations of the Chair of Measurement and Testing Techniques Technical University of Dresden, Germany Dec. 2014.
81. N. A. Riza, Invited Seminar on " Advanced Imagers," Faculty of Engineering, Koc University, Istanbul, Turkey, Dec. 2014.
82. N. A. Riza, Seminar on "Agile Pixel Imagers," Faculty of Applied Sciences Distinguished Lecture, Technical University of Delft, Netherlands Feb. 2015.
83. N. A. Riza, "Inventing with Light: A Personal Journey," UNESCO Year of Light and Light Technologies Plenary Speech at the Light and Life Symposium, Islamabad, Pakistan, Oct. 2015.
84. N. A. Riza, "Inventing with Light: A Personal Journey," Invited Speech at the School of Electrical Engineering and Computer Science, National University of Technology (NUST), Islamabad, Pakistan, Oct. 2015.
85. N. A. Riza, "Light – Empowering the Life of an Inventor," LUMS School of Science and Engineering, August 2016.
86. N. A. Riza, "CAOS Smart Camera – Empowering Extreme Imaging," Nokia Bell Laboratories, Crawford Hill and Murray Hill Sites, April 3, 2017.

87. N. A. Riza, “CAOS Smart Camera – Empowering Extreme Imaging,” Princeton University, April 4, 2017.
88. N. A. Riza, “CAOS Smart Camera – Empowering Extreme Imaging,” Invited International Webinar hosted by Photonics Media USA , April 26, 2017.
89. N. A. Riza, “CAOS Smart Camera – Empowering Automotive Imaging,” Plenary Invited Speaker , AutoSense Conference, Brussels, Sept 21, 2017.
90. N. A. Riza, “CAOS Smart Camera – Empowering Surveillance and Automotive Imaging,” Opening Session Plenary Invited Speaker, Photonics in 2017 Conference, Las Vegas, Nov., 2017.
91. N. A. Riza, “Advances in CAOS Camera Imaging,” Invited Plenary Speaker, European Conference on Laser Optics & Photonics, Prague, Czech Rep., July 16-17, 2018.
92. N. A. Riza, 2019 Land Medal Winner Talk on Camera Optics: “The CAOS Camera – Empowering Full Spectrum Extreme Linear Dynamic Range Imaging,” Invited Speaker E. H. Land Medal Speech, International Society for Imaging Science and Technology (IS & T) 27th Color and Imaging Conference (CIC), Paris, France, Oct.25, 2019.

Other Publications (10):

1. N. A. Riza, Special Issue Guest Editor of the SPIE Optical Processing Working Group NewsLetter on the Topic Photonics and Phased Array Systems (PAPAS), Vol.10, No.1, April 1999.

2. N. A. Riza, "Coherent Optical Correlator with Wideband Signal Processing Capabilities," *SPIE's International Technical Working Group on Optical Processing & Computing Newsletter*, Nov., 1993.

3. N. A. Riza, Special Issue Guest Editor of the SPIE Optical Processing Working Group NewsLetter on the Topic "Freespace Optical Wireless," October 2001.

4. N. A. Riza, Organizer and Chair, 2002 IEEE LEOS Annual Meeting Special Symp. of Agile Laser Beams and Applications, Glasgow, Scotland, Nov. 2002.

5. N. A. Riza, Organizer and Panel Chair: Optical Devices - Research Perspectives from the School of Optics/CREOL at the University of Central Florida, 2003 National Fiber Optics Engineers Conference (NFOEC), Sept.10, Orlando, FL 2003.

6. N. A. Riza, "Prof. Hermann Haus Memorial," IEEE LEOS News Letter Magazine, August 2003. http://www.ieee.org/organizations/pubs/newsletters/leos/aug03/haus.html

7. N. A. Riza, "Growth by Empowering Student Members," IEEE LEOS News Letter Magazine, Feb. 2005. http://www.ieee.org/organizations/pubs/newsletters/leos/feb05/growth.html

8. Mechanical Profilers Go Digital by N. A. Riza, LaserFocus World Magazine, August 2004.

9. Seeing the Unseen with the CAOS Camera by N. A. Riza, Engineers Ireland Magazine, Nov. 2016.
10. The CAOS Smart Camera – Empowering Extreme Imaging by N. A. Riza, Photonics Spectra USA Magazine, March 2017.

APPENDIX

NABEEL AGHA RIZA 2021 INTERNATIONAL INDUCTEE OF THE UK's ROYAL ACADEMY OF ENGINEERING

https://www.raeng.org.uk/news/news-releases/2021/september/academy-celebrates-first-new-fellows-elected-under

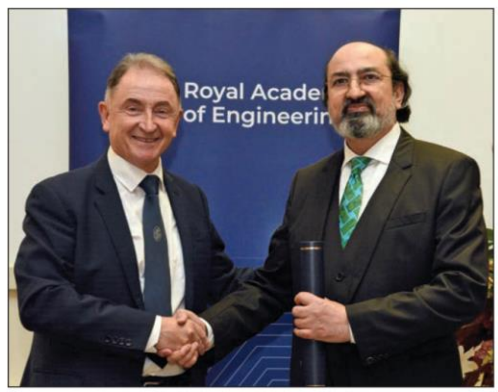
(IEEE Photonics Society News Magazine, Dec. 2021)

Careers and Awards

Royal Academy of Engineering Inducts IEEE Photonics Society Fellow, Professor Nabeel Agha Riza

IEEE Photonics Society Fellow and Chair Professor of Electrical & Electronic Engineering, Nabeel A. Riza of University College Cork, Ireland was inducted into the Royal Academy of Engineering, UK's National Academy of Engineering. Induction to the Academy is a prestigious UK honor awarded to high impact engineering professionals. Membership is diverse and includes Nobel Prize winners and UK's Lewis Hamilton, 6-time Formula One Racing World Champion. Riza was elected as a global prize-winning inventor of light-based technologies including invention of the all-digital fault-tolerant fiber-optic equalizer deployed in the global internet. Sir Jim McDonald, President of the Academy stated: "*Our Fellows represent the best of the best in the engineering world.*" The induction ceremony was held 11 October, Prince Philip House, London.

For more information on the Royal Academy of engineering please visit: https://bit.ly/3CAAOHi



December 2021 *IEEE PHOTONICS SOCIETY NEWSLETTER* 21

OPTICA/OSA OPN Magazine Member News, Jan. 2022

RAE Induction for Nabeel Riza

Optica Fellow **Nabeel A. Riza**, chair professor of electrical and electronic engineering, University College Cork, Ireland, was inducted into the UK Royal Academy of Engineering. Induction to the academy is a prestigious UK honor awarded to high-impact engineering professionals. Riza was elected as a global prize-winning inventor of light-based technologies, including the invention of an all-digital fault-tolerant fiber optic equalizer deployed in the global internet. The induction ceremony was held on 11 October in London.

NABEEL AGHA RIZA 2020 INDUCTEE OF THE ROYAL IRISH ACADEMY

https://www.ria.ie/news/membership/29-new-members-admitted

(IEEE Photonics Society News Magazine, June 2020)

Royal Irish Academy Inducts IEEE Photonics Society Fellow, Professor Nabeel Agha Riza

IEEE Photonics Society Fellow and Chair Professor of Electrical & Electronic Engineering, Nabeel Agha Riza of University College Cork, Ireland was inducted into the Royal Irish Academy (RIA) on May 22, 2020. Induction to the Academy in the highest honor awarded to scholars in Ireland across all disciplines that including physical sciences, social sciences, humanities, and medicine. The RIA was founded in 1785 and famed past members include mathematician Sir William Rowan Hamilton and physicist Erwin Schrödinger. Riza is acknowledged for his contributions to both research and education internationally and in Ireland as a photonics inventor impacting key areas of technology in imaging, communications, energy and aerospace systems.

For RIA May 22,2020 Press Release Please Go To https://www.ria.ie/news/membership/29-new-members-admitted

(OSA International Optical Society News OPN Magazine, July 2020)

Nabeel Riza Joins the Royal Irish Academy

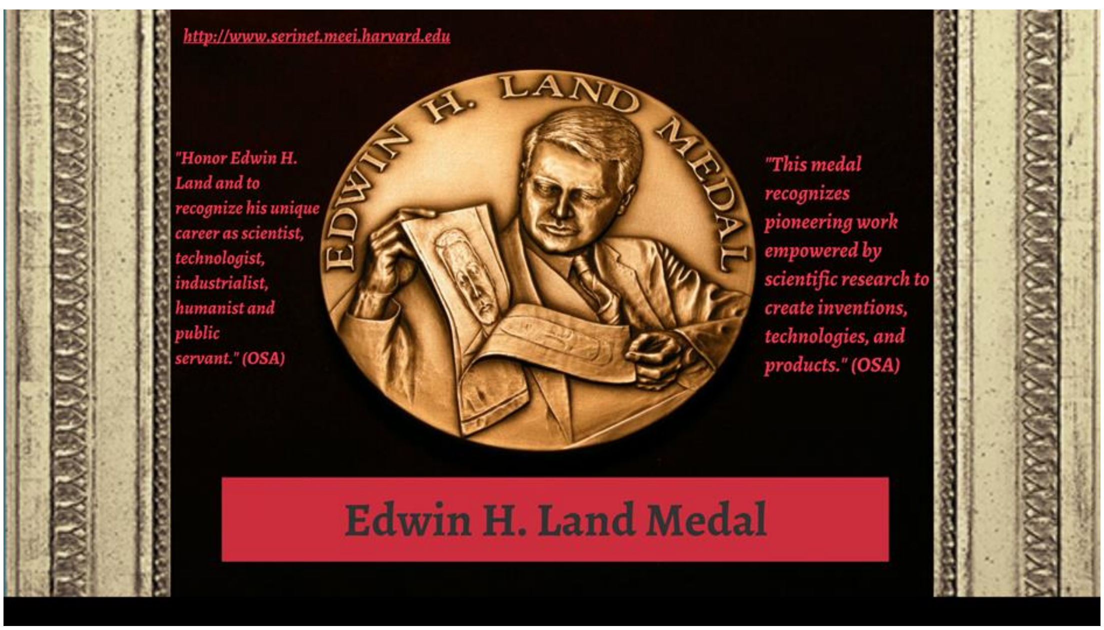
Congratulations to OSA Fellow **Nabeel Riza**, University College Cork, Ireland, who was named a 2020 Inductee of the Royal Irish Academy (RIA), the highest National Academy in Ireland. Riza is acknowledged for his contributions to both research and education in Ireland as well as for his international career as a leading photonics inventor impacting key areas of technology in imaging, communications, energy and aerospace systems. The RIA Induction Ceremony was held virtually on 22 May.

University College Cork

2019 OSA/IS&T EDWIN H. LAND MEDAL WINNER: NABEEL AGHA RIZA

(OSA Public Press Release link below, dated March 29, 2019)

https://www.osa.org/en-us/about_osa/newsroom/news_releases/2019/osa_and_is_t_name_nabeel_agha_riza_2019_edwin_h_la/



The Edwin H. Land Medal jointly from the International Optical Society (OSA) and the Society for Imaging Science and Technology (IS&T) honors Edwin H. Land to recognize his unique career as scientist, technologist, industrialist, humanist and public servant. This medal recognizes pioneering work empowered by scientific research to create inventions, technologies, and products. The recipient(s) should share Land's insatiable scientific intensity and curiosity in optics and imaging and, in part, reflect his image as inventor, scientist, entrepreneur, and teacher. The Land Medal is partly endowed by the Polaroid Foundation. Dr. Land founded Polaroid Corporation and is reknown as the inventor of the Polaroid camera and the plastic sheet polarizer. Previous famed winners of the Land Medal include the CCD camera inventors G. Smith and W. Boyle who were awarded the Physics Nobel Prize.

Prof. Riza is the sole winner of the 2019 OSA/IS& T Edwin H. Land Medal. The Citation for Prof. Riza reads:

*"**for the invention and commercialization of pioneering macro- and micro-scale imaging techniques across RF and optical wavelengths, and the education and mentoring of distinguished scientists and engineers.**"*

(OSA Public Press Release link below for 2019 Land Medal, dated March 29, 2019)

https://www.osa.org/en-us/about_osa/newsroom/news_releases/2019/osa_and_is_t_name_nabeel_agha_riza_2019_edwin_h_la/

OSA and IS&T Name Nabeel Agha Riza the 2019 Edwin H. Land Medal Recipient

The Optical Society and Society for Imaging Science and Technology cite honoree for invention and commercialization of imaging techniques, education and mentoring

WASHINGTON — The Optical Society (OSA) and the Society for Imaging Science and Technology (IS&T) are pleased to name Nabeel Agha Riza, University College Cork (UCC), Ireland the 2019 Edwin H. Land Medal winner. Riza is recognized for inventing and commercializing pioneering macro- and micro-scale imaging techniques across RF and optical wavelengths, as well as the education and mentoring of distinguished scientists and engineers.

"***Nabeel Riza is both a prolific inventor of imaging methodology and a gifted educator," said 2019 OSA President Ursula Gibson. "The Edwin H. Land Medal is proper acknowledgment of his many contributions to the field of applied optics and to the education and development of new generations of researchers and inventors in this field***."

Riza graduated in 1984 from the Illinois Institute of Technology, U.S.A., with a bachelor's degree in electrical engineering. He received Master's and Ph.D. degrees from California Institute of Technology (Caltech), U.S.A., in 1985 and 1989, respectively. He currently holds the Chair Professorship in Electrical and Electronic Engineering at UCC.

Riza is a recipient of the 1994 GE Gold Patent Medal, 2001 ICO Prize & Carl Zeiss E. Abbe Medal; 2008 Berthold Leibinger Innovationspreis Finalist Distinction Award; 2009 IEEE Photonics Society Distinguished Lecturer Award; 2009 Ireland Walton Award; 2018 IET Achievement Medal and Honorary Fellow Award of Engineers Ireland Society. He is a Fellow of OSA, IEEE, SPIE, IET: The Institution of Engineering & Technology; the European Optical Society and the U.S. National Academy of Inventors. He holds 46 U.S. patents, is the author of 340 journal and conference papers and the textbook, "*Photonic Signals and Systems: An Introduction*."

For 30 years, Riza has made pioneering innovations in applied optics with several of his inventions deployed worldwide. These include the CAOS (Coded Access Optical Sensor) camera; the camceiver; on-chip embedded controls liquid crystal lens; multiplexed optical scanner technology; self-aligning acousto-optic interferometry & RF signal processors; low-noise liquid crystal switches and all-digital attenuators. He also invented a photonically controlled ultrasonic imaging probe, fault-tolerant digital MEMS fiber-optic signal controls, agile indoor optical wireless, electronic or e-lens-based vision testing, microscopy, and 3-D imaging; self-imaging freespace-fiber-optic coupling model; analog-digital fiber-optic RF phased array antenna imaging; agile pixel MEMS imager and e-lens laser beam propagation analyzer and interferometry-pyrometry silicon carbide extreme temperature thermometry.

Established in 1992, the Edwin H. Land Medal recognizes pioneering work empowered by scientific research to create inventions, technologies and products. It honors Edwin H. Land for his unique career as scientist, technologist, industrialist, humanist and public servant. The medal is jointly presented by OSA and IS&T, and funded through the support of the Polaroid Foundation, the Polaroid Retirees Association and individual contributors, including Manfred Heiting, Theodore Voss and John J. McCann.

About The Society for Imaging Science and Technology
IS&T is an international professional non-profit dedicated to keeping members and other imaging professionals apprised of the latest developments in the field through conferences, educational programs, publications, and its website. IS&T programs encompass all aspects of the imaging workflow, which moves from capture (sensors, cameras) through image processing (image quality, color, and materialization) to hard and soft copy output (printing, displays, image permanence), and includes aspects related to human vision, such as image quality and color. The Society also focuses on a wide range of image-related applications, including security, virtual reality, machine vision, and data analysis. For more information, visit imaging.org.

About The Optical Society
Founded in 1916, The Optical Society (OSA) is the leading professional organization for scientists, engineers, students and entrepreneurs who fuel discoveries, shape real-life applications and accelerate achievements in the science of light. Through world-renowned publications, meetings and membership initiatives, OSA provides quality research, inspired interactions and dedicated resources for its extensive global network of optics and photonics experts. For more information, visit osa.org.

Media Contact:

mediarelations@osa.org

(IS & T Public Press Release below for 2019 Land Medal, dated April 02, 2019)

Professor Nabeel Agha Riza Receives Edwin H. Land Medal

SPRINGFIELD, VA (PRWEB) APRIL, 2019

Nabeel Agha Riza, Chair Professor of Electrical and Electronic Engineering (EEE) at University College Cork (UCC), Ireland, has been awarded the 2019 Edwin H. Land Medal for the invention and commercialization of pioneering macro- and micro-scale imaging techniques across RF and optical wavelengths, and the education and mentoring of distinguished scientists and engineers.

The award was established in 1992 by the Society for Imaging Science and Technology (IS&T) and The Optical Society (OSA) to honor Edwin H. Land, inventor, vision scientist, entrepreneur and founder of the Polaroid Corporation. The prize is awarded annually and recognizes pioneers in scientific research whose work has enabled new inventions, technologies, and products.

As a Caltech PhD-educated industrial engineer, professor, entrepreneur, and volunteer, Riza has been making pioneering innovations in the field of photonics for more than 30 years. Riza's inventions include the CAOS camera, fault-tolerant digital MEMS fiber-optics, agile optical wireless, electronic lens-based vision testing and imaging, self-imaging fiber coupling model, liquid crystal and analog-digital fiber-optic RF antenna control, agile pixel MEMS laser beam profiler and 3-D analyzer, and hybrid design Silicon Carbide extreme thermometry.

Riza holds 46 issued patents—28 as single inventor—and has 334 international publications (including 154 journal papers) and 92 invited talks. For his high-impact inventions, Riza was inducted in 2017 into the United States National Academy of Inventors (NAI). He is a pioneer in the use of optical beamforming techniques for RF imaging phased array radars and optical imagers.

Riza recently invented the CAOS smart camera – a paradigm changing imager design using principles of the RF mobile phone multi-access wireless network that provides world record extreme linear dynamic range, inherent image security, extremely low inter-pixel crosstalk, and full spectral flexibility in one unit not possible in classic CMOS, CCD, FPA cameras. He is scheduled to give a keynote address on this at the IS&T 27th Color and Imaging Conference (CIC) to be held in Paris 21–25 October 2019.

In addition to his many innovations, Riza has educated engineers who have gone on to win awards and develop successful careers at top industrial and academic research positions at Caltech, MIT, Princeton, Apple, Carl Zeiss, GE, and TI. One of them (M. Arain) also contributed to the LIGO-based gravitational wave discovery that won the 2017 Nobel Prize. In 2013, Riza wrote the textbook *Photonic Signals and Systems: An Introduction,* to teach students the basics and art of design of photonic modules and systems.

Riza is the recipient of the International Optics Commission 2001 ICO Prize; Carl Zeiss Foundation 2001 Abbe Medal; 1994 GE Gold Patent Medal; 2007 EU Erasmus Mundus Visiting Scholar Award; 2009 IEEE Photonics Society Distinguished Lecturer Award; 2008 German Berthold Leibinger Innovation Prize Nominee Distinction Award; 2018 IET Achievement Medal; and the 2009 Ireland Walton Award. Riza is a Fellow of IEEE, IET, the European Optical Society, OSA, and SPIE; an Honorary Fellow of Engineers Ireland Society; and a member of the Royal Irish Academy (RIA) Engineering Committee.

The Edwin H. Land Medal is funded through the support of the Polaroid Foundation, the Polaroid Retirees Association and individual contributors, including Manfred Heiting, Theodore Voss, and John J. McCann.

About IS&T

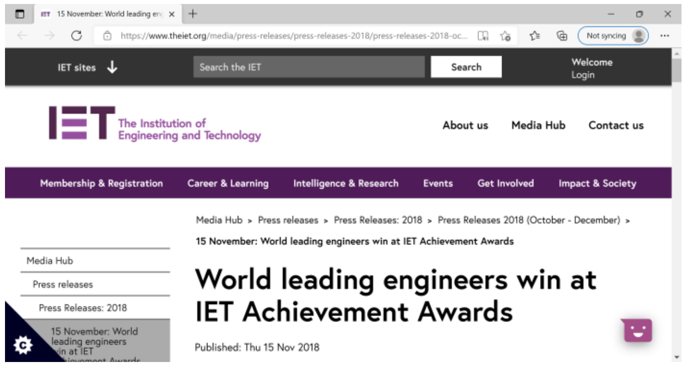
The Society for Imaging Science and Technology (IS&T) is an international professional non-profit dedicated to keeping members and other imaging professionals apprised of the latest developments in the field through conferences, educational programs, publications, and its website. IS&T programs encompass all aspects of the imaging workflow, which moves from capture (sensors, cameras) through image processing (image quality, color, and materialization) to hard and soft copy output (printing, displays, image permanence), and includes aspects related to human vision, such as image quality and color. The Society also focuses on a wide range of image-related applications, including security, virtual reality, machine vision, and data analysis. Follow us on Twitter @ImagingOrg.

About The Optical Society

Founded in 1916, The Optical Society (OSA) is the leading professional organization for scientists, engineers, students and business leaders who fuel discoveries, shape real-life applications and accelerate achievements in the science of light. Through world-renowned publications, meetings and membership initiatives, OSA provides quality research, inspired interactions and dedicated resources for its extensive global network of optics and photonics experts. For more information, visit osa.org.

PRESS RELEASE ON 2018 IET ENGINEERING ACHIEVEMENT MEDAL

https://www.theiet.org/media/press-releases/press-releases-2018/press-releases-2018-october-december/15-november-world-leading-engineers-win-at-iet-achievement-awards/

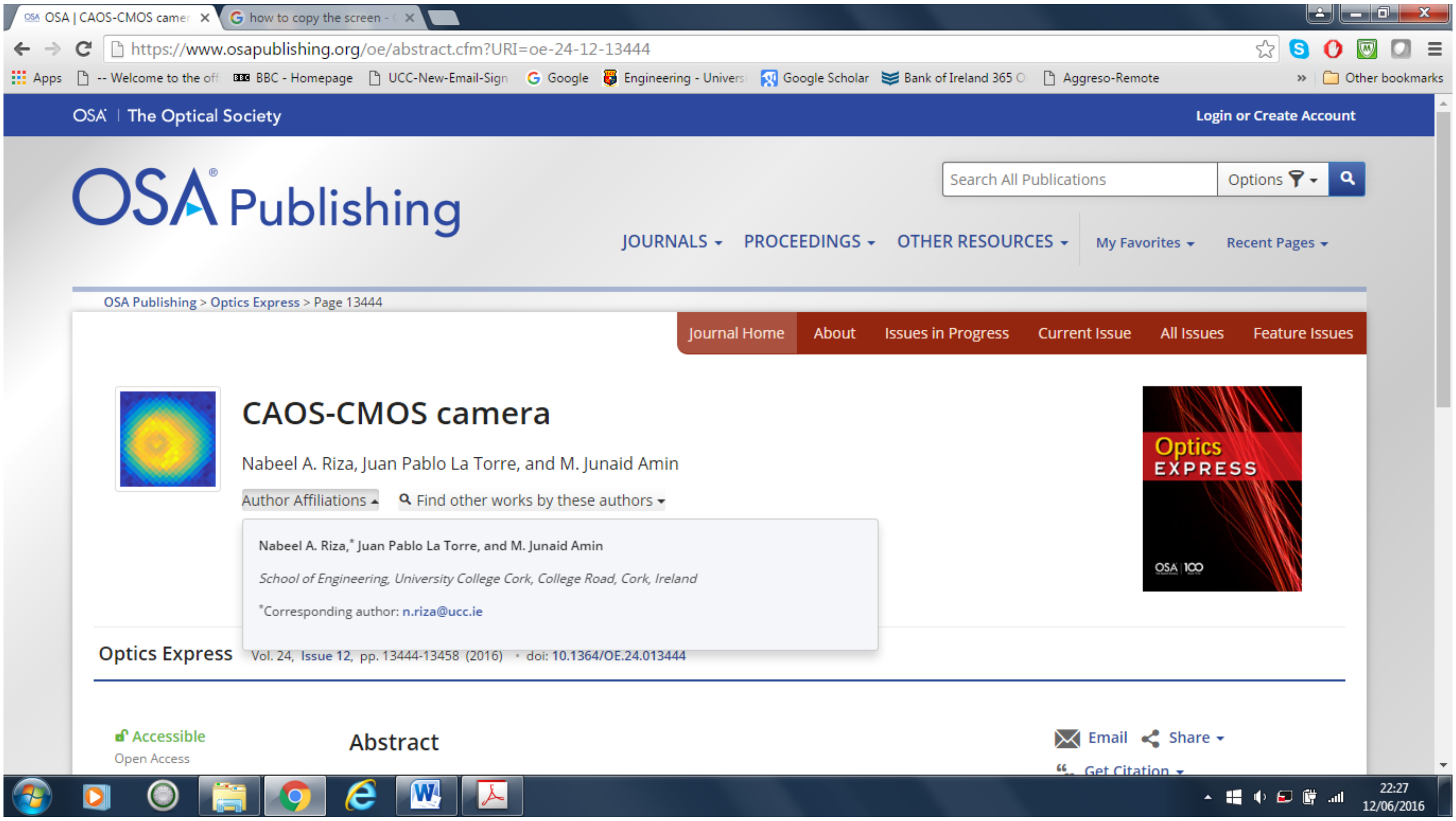


Nov.17, 2018, Cork, Ireland.

The IET (Institution for Engineering & Technology) at the IET awards ceremony in London has awarded Professor Nabeel A. Riza, the IET Achievement Medal for Photonics. The IET Achievement Medals are globally competitive and awarded to individuals who have made major and distinguished contributions with sustained excellence in the various sectors of science, engineering and technology. The IET states: These awards recognise some of the world's most outstanding engineers and technologists. Founded in 1871, the IET (formerly IEE) headquartered in London is one of the largest engineering organizations in the world with former distinguished Presidents that include German-born engineer and entrepreneur Carl Wilhelm Siemens and Belfast-born inventor and electrical engineer William Thomson (Lord Kelvin). **The IET Achievement Medal citation states:** "Professor Riza has made photonic design breakthroughs for over 30 years. He has pioneered and invented Liquid Crystal, Acousto-optic and Digital Micromirror Device-enabled smart and robust optically engineered module designs, including low loss fibre coupling models and resistive electrode liquid crystal lenses that have greatly advanced RF photonics antenna controls, optical fibre and optical wireless communications and optical imaging systems.

RECENT INVENTION BY PROF. N. RIZA - THE CAOS CAMERA TECHNOLOGY

Recent Publication: CAOS-CMOS Camera, OSA Optics Express, June 9, 2016.



Abstract

Proposed and experimentally demonstrated is the CAOS-CMOS camera design that combines the coded access optical sensor (CAOS) imager platform with the CMOS multi-pixel optical sensor. The unique CAOS-CMOS camera engages the classic CMOS sensor light staring mode with the time-frequency-space agile pixel CAOS imager mode within one programmable optical unit to realize a high dynamic range imager for extreme light contrast conditions. The experimentally demonstrated CAOS-CMOS camera is built using a digital micromirror device, a silicon point-photo-detector with a variable gain amplifier, and a silicon CMOS sensor with a maximum rated 51.3 dB dynamic range. White light imaging of three different brightness simultaneously viewed targets, that is not possible by the CMOS sensor, is achieved by the CAOS-CMOS camera demonstrating an 82.06 dB dynamic range. Applications for the camera include industrial machine vision, welding, laser analysis, automotive, night vision, surveillance and multispectral military systems.

www.laserfocusworld.com August 2016

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CMOS CAMERAS

CAOS-CMOS camera has 1000X better dynamic range

Nabeel A. Riza, head of the School of Engineering and chair professor of Electrical and Electronic Engineering (EEE) at University College Cork (UCC; Cork, Ireland), and colleagues have demonstrated the coded access optical sensor (CAOS) complementary metal-oxide semiconductor (CMOS), or CAOS-CMOS, camera with a three-orders-of-magnitude (or factor of 1000) improvement in camera dynamic range when compared to a conventional CMOS camera.[1] Using extremely bright and high-contrast test targets, it was demonstrated that the potentially high-speed camera has exceptionally low interpixel crosstalk and—using silicon-based photodetection—can operate from the ultraviolet (UV) to the near-infrared (near-IR) wavelength region.

High-contrast imaging

Major manufacturers have previously demonstrated CMOS multipixel sensor research devices with 80 dB dynamic range using a variety of techniques, including pixel-level light integration time and electronic gain controls, as well as by doubling sensor chip pixel size for larger quantum wells in rolling-shutter designs. However, imagers that function well beyond 80 dB are needed—especially for high-contrast (greater than 10⁴:1) imaging applications such as welding, laser-beam profiling, combustion events, night vision, biological microscopy, and machine vision.

The CAOS-CMOS camera design uses electronic and optical pixel manipulation in both the space and time/frequency domain to form agile pixels that selectively act on CMOS sensor-guided regions of the image to observe unseen high-contrast features.

Light from an external object is directed by a lens (L1) onto the agile pixels plane of a programmable digital micromirror device (DMD). To initiate the imaging operation, the DMD micromirrors are set to spatially route the incident light to the CMOS sensor to create an initial target-scene irradiance map. Based on this initial image intelligence, the DMD is programmed in its CAOS mode to create specifically located agile pixels that sample image zones of interest.

This agile-pixel programming capability via the DMD allows the agile

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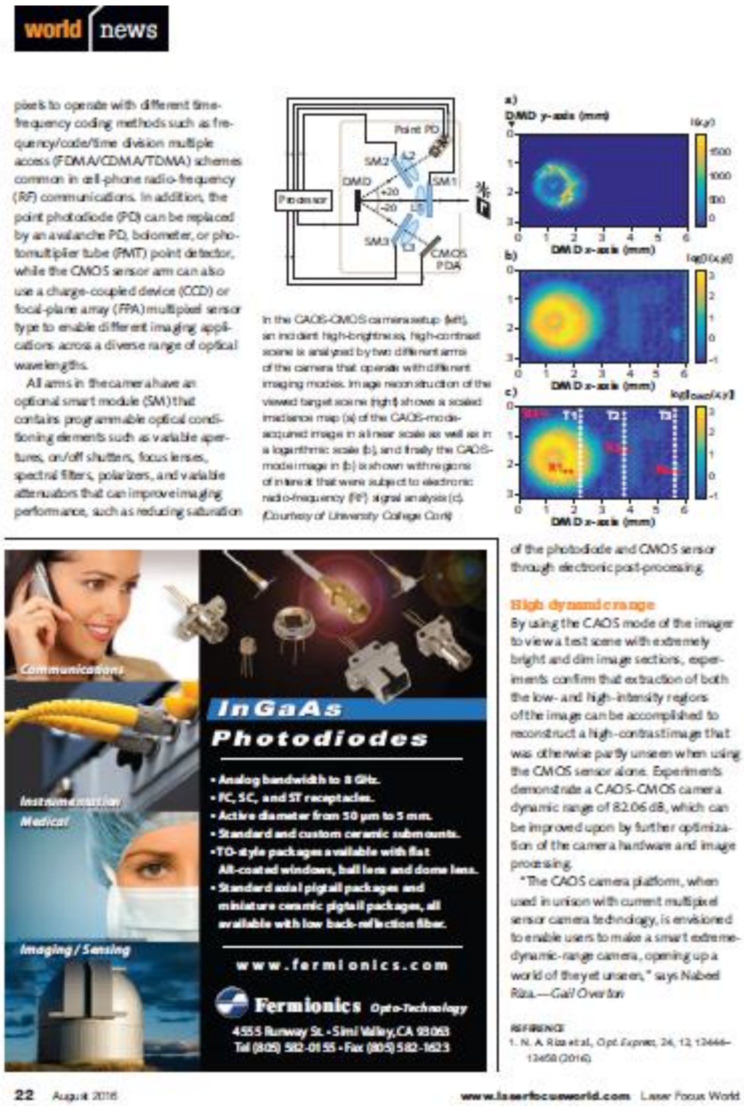


world news

pixels to operate with different time-frequency coding methods such as frequency/code/time division multiple access (FDMA/CDMA/TDMA) schemes common in cell-phone radio-frequency (RF) communications. In addition, the point photodiode (PD) can be replaced by an avalanche PD, bolometer, or photomultiplier tube (PMT) point detector, while the CMOS sensor arm can also use a charge-coupled device (CCD) or focal-plane array (FPA) multipixel sensor type to enable different imaging applications across a diverse range of optical wavelengths.

All arms in the camera have an optional smart module (SM) that contains programmable optical conditioning elements such as variable apertures, on/off shutters, focus lenses, spectral filters, polarizers, and variable attenuators that can improve imaging performance, such as reducing saturation of the photodiode and CMOS sensor through electronic post-processing.

In the CAOS-CMOS camera setup (left), an incident high-brightness, high-contrast scene is analyzed by two different arms of the camera that operate with different imaging modes. Image reconstruction of the viewed target scene (right) shows a scaled irradiance map (a) of the CAOS-mode-acquired image in a linear scale as well as in a logarithmic scale (b), and finally the CAOS-mode image in (b) is shown with regions of interest that were subject to electronic radio-frequency (RF) signal analysis (c). (Courtesy of University College Cork)

High dynamic range

By using the CAOS mode of the imager to view a test scene with extremely bright and dim image sections, experiments confirm that extraction of both the low- and high-intensity regions of the image can be accomplished to reconstruct a high-contrast image that was otherwise partly unseen when using the CMOS sensor alone. Experiments demonstrate a CAOS-CMOS camera dynamic range of 82.06 dB, which can be improved upon by further optimization of the camera hardware and image processing.

"The CAOS camera platform, when used in unison with current multipixel sensor camera technology, is envisioned to enable users to make a smart extreme-dynamic-range camera, opening up a world of the yet unseen," says Nabeel Riza.—*Gail Overton*

REFERENCE
1. N. A. Riza et al., *Opt. Express*, 24, 12, 13444–13458 (2016).

CAOS Camera Selected by The International Optical Society (OSA) 2016 Breakthrough in Imaging, Dec. OSA OPN Optics in 2016 Special Issue (see next page)

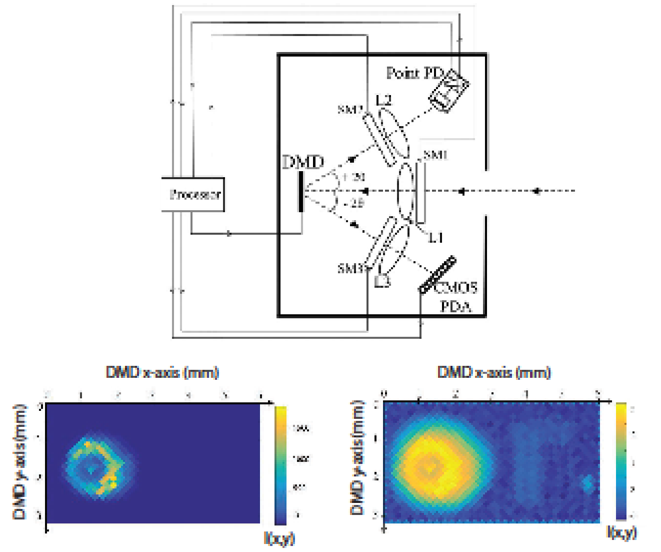
IMAGING

H-CAOS Camera

Recent advances in visible-band CMOS and CCD camera designs have produced high-dynamic-range (HDR) operations (e.g., 80 dB), through electronic control of individual-pixel integration time and pixel electronic-gain control or by acquiring multiple images and computationally reconstructing the scene. Yet achieving even higher dynamic ranges—while maintaining optical spectrum flexibility, minimal inter-pixel crosstalk and the potential for high-speed imaging—remains a challenge. We have developed a camera technology, the coded access optical sensor (CAOS), that works in combination with today's multi-pixel imaging sensors to pull out previously unseen image features.[1]

Unlike current CCD or CMOS cameras, the CAOS camera exploits the extreme dynamic range of electronic wireless-style processing. It does this using time–frequency encoding of "agile" pixels in the image space, followed by time–frequency decoding via electronic processing to extract and manipulate the pixel light intensity information.

Essentially, agile pixels in the multi-pixel CAOS image map have specific spatial parameters (such as pixel position, size and shape) as well as specific time–frequency-modulated "telephone number" codes. A single optical antenna/receiver simultaneously detects these pixels, represented as RF-modulated light signals, and, through electronic decoding, rapidly recovers all the deployed agile-pixel light levels. A multi-pixel imaging sensor works with the CAOS camera to provide imaging intelligence that enables space–time electronic programming of agile pixels, for fast extraction of bright, high-contrast targets of interest.



(Top) H-CAOS camera design using a CMOS photodetector array (PDA) as the hybrid element. L1/L2/L3, lenses; SM1/SM2/SM3, "smart" modules for light conditioning; PD, photodetector with amplifier. (Bottom) 82 dB HDR scaled irradiance map of a CAOS-mode acquired image in a linear (left) and logarithmic (right) scale. While the linear scale shows only one target, the logarithmic scale shows that the H-CAOS setup actually picked up all three targets in an HDR scene with extreme contrasts.

A recently demonstrated, hybrid-element version of the CAOS camera—the H-CAOS or CAOS-CMOS camera—uses a digital micromirror device (DMD) as the CAOS-mode space–time–frequency agile-pixel encoder. The DMD is programmed to direct the incident light to the camera arm with a CMOS photodetector array. Initial scene information is gathered and used to program the DMD in CAOS-mode, thus seeking out the desired pixel HDR regions of the scene. This visible-band camera demonstrated an improvement of three orders of magnitude in camera dynamic range over a commercial CMOS camera when subjected to three test targets that created a HDR scene with extreme brightness as well as extreme contrast (more than 82 dB).

We believe that the CAOS camera platform, used in unison with current multi-pixel sensor camera technology, can enable development of "smart" cameras with extreme dynamic ranges (greater than 140 dB), opening up a world of the yet-unseen across diverse applications. OPN

RESEARCHERS

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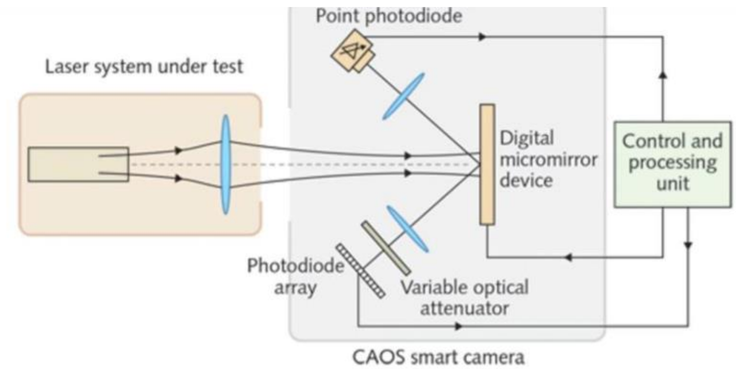
1. N. A. Riza et al. Opt. Express 24, 13444 (2016).

Beam Characterization: CAOS camera images laser beams with extremely high dynamic range

In its many configurations, the CAOS camera images laser beams in different ways that match differing system requirements.

Author — John Wallace

Nov 1st, 2018



A coded access optical sensor (CAOS) camera for laser-beam imaging has at its heart a digital micromirror device (DMD) in which various combinations of pixels can be switched on and off to fulfill the requirements of different coding schemes.

Accurate laser-beam characterization is essential for developing, qualifying, and testing lasers for myriad of uses. Traditional methods of looking at a laser beam include imaging the attenuated beam with a CMOS or CCD camera, as well as knife-edge, moving slit, and moving pinhole scanning techniques. Each of these forms has distinct advantages and disadvantages for different applications—as a result, different types of beam-characterization equipment are available on the market. In addition to existing hardware, new forms of beam characterization are being developed to best solve certain problems.

For example, some laser applications require 2D characterization of a beam over a high dynamic range. One traditional way of doing this is by using a 2D-scanned pinhole paired with a sensitive photodiode—however, this method is quite slow and requires high-precision scanning of the pinhole. An approach that is simpler in some ways is the use of a digital micromirror device (DMD), which is a 2D array of tiltable microelectromechanical systems (MEMS) micromirrors that can replace the function of a scanned pinhole, as each mirror can be tilted one by one to turn that particular pixel on or off. But this approach, although

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mechanically straightforward, is still slow.

Recently, researchers have improved the speed of the DMD-type setup by introducing various coding schemes to the DMD pixel modulation, resulting in what is called the coded-access optical sensor (CAOS) camera (which can actually be used with incoherent as well as coherent light for other imaging uses). Coding schemes for laser-beam imaging have included frequency-division multiple-access (FDMA) and time-division multiple-access (TDMA) modes.

Comparing different image-acquisition modes

Now, Nabeel Riza and Mohsin Mahzar of University College Cork (Cork, Ireland) have compared several of these image-acquisition modes, including some for the first time.[1] The imaging modes include TDMA, code division multiple access (CDMA), the CDMA-TDMA mode, the FDMA-TDMA mode, the frequency modulation FM-CDMA-TDMA mode, the FM-TDMA mode, and the FDMA-CDMA-TDMA mode. For example, the CDMA approach involves turning specific combinations of pixels on and off while recording the resulting total intensity with the photodiode—a computer algorithm then decodes the data and produces an intensity map. In a

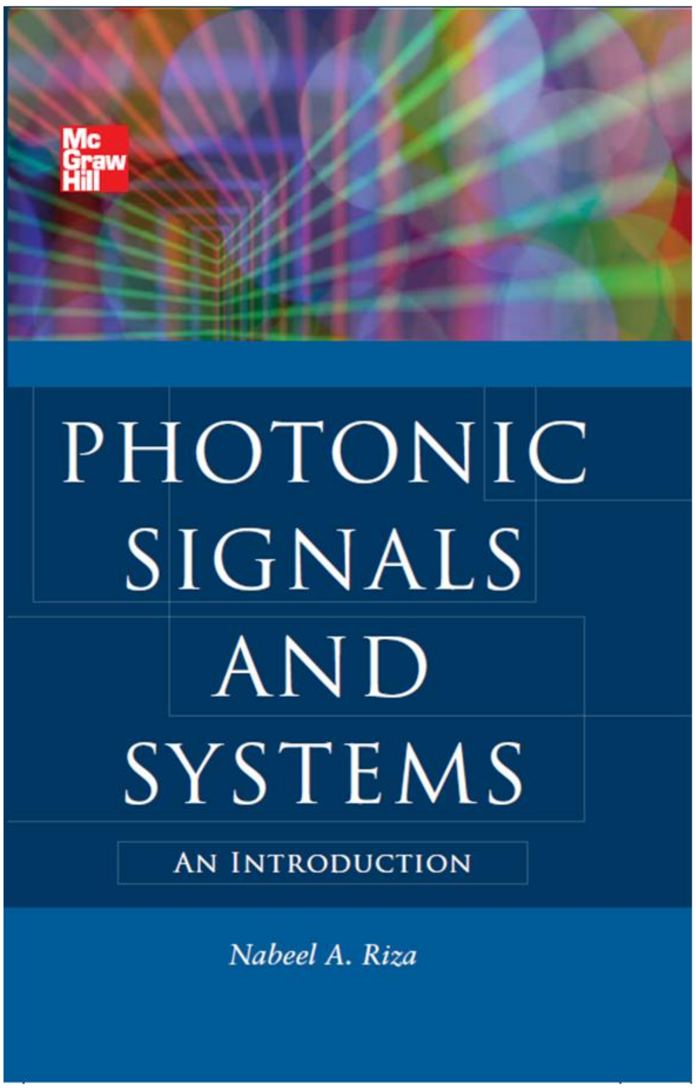
REFERENCE

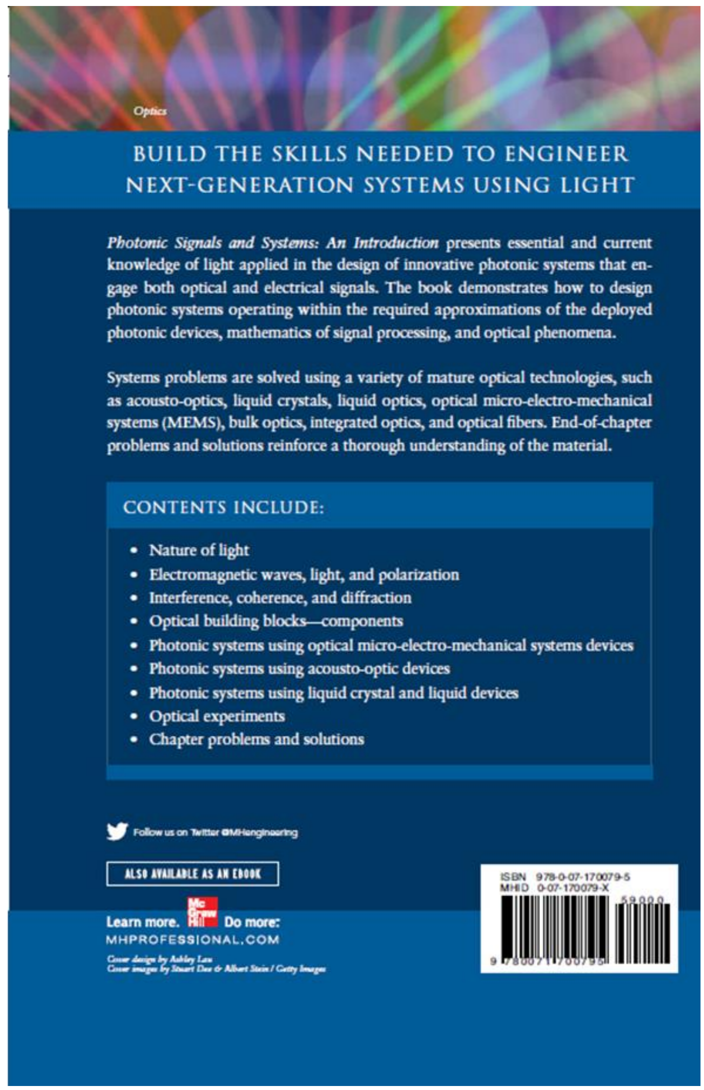
1. N. A. Riza and M. A. Mahzar, *Appl. Opt.* (2018); https://doi.org/10.1364/ao.57.000e20.

FREE RIZA TEXTBOOK OFFERED FOR DOWNLOADS

Starting May 16, 2020, to celebrate the **UNESCO Day of LIGHT** and to Assist Students and Researchers worldwide under stress during the COVID-19 Pandemic and in particular, in developing countries, Prof. Riza provided charge free access to his Photonics Signals and Systems TextBook and its Teaching Materials and Problem Solutions that have so far had over 700 downloads. The Book material is available indefinitely for **free downloads** at:

http://nabeelriza.com/teachingmaterials/





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