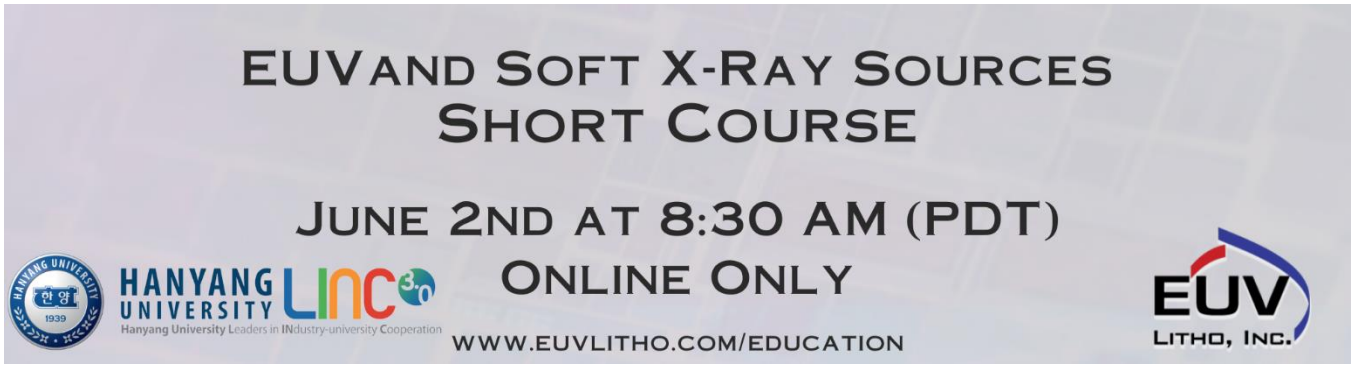

EUV and Soft X-ray Sources Short Course

Course Overview

This short course on EUV and Soft X-ray Sources will give an overview of underlying physics associated with EUV Lithography and EUV and soft X-ray plasma sources. This course will give an overview of the underlying physics associated with EUVL and plasma sources. This short course will be taught by Prof. Gerry O'Sullivan (UC Dublin), Prof. Marcelo Ackermann (University of Twente),). Prof. Henry Kapteyn (K&M Labs) and Prof. Bjorn Manuel Hegelich (UT Austin).

Registration Link

https://euvlitho.regfox.com/2024-euv-and-soft-x-ray-sources-short-course

Course Material

Students will be mailed a copy of the textbook are encouraged to purchase the text, Photon Sources for Lithography and Metrology, directly from SPIE, after the short course.

Intended Audience

This short course is intended for anyone who is involved in the development of EUV Lithography and/or other emerging lithography or metrology techniques for lithography, biology or material science or any other applications that involve EUV or Soft X-ray photons. This course will help students understand the fundamentals, technology requirements, current and future trends. Those who are responsible for the development of the technology roadmaps and making technology decisions as well as students and engineers will find this course valuable.

Detailed Course Outline

Module 1: Physics of EUV and Short Wavelength Sources with Focus on Atomic Physics (Prof. Gerry O'Sullivan, School of Physics, UCD, Dublin) (2 Hours)

This module will cover basic properties of laser produced and discharge produced plasmas and plasma models. We will review experimental factors determining plasma parameters and ion stage distributions, emission processes, line and continuum emission and UTA (unresolved transition array) emission. Topics covered also include: basic properties of H-like and He-like systems, coupling schemes and spectroscopic notation, transition probabilities and line intensities, calculations of atomic structure and spectra, complex spectra and UTAs, configuration interaction effects, opacity and radiation transport, UTA emission in sources for EUV and BEUV lithography, optimizing UTA emission, evolution of UTA emission with atomic number; implications for water-window operation, 3d-4f versus 4d-4f UTAs as water-window sources and a survey of short wavelength emission spectra.

Module will cover:

1. Basic plasma properties and processes
2. Physics of EUV radiation processes
    - Line and continuum spectra
    - Transition probabilities
    - Unresolved transition arrays (UTA)
    - Opacity issues
    - Scaling of emission with ion stage and atomic number
3. Optimization of emission from 13.5 nm and BEUV lithography sources
4. Challenges for EUV and short wavelength operation, comparison of LPP and DPP sources.
5. Brief introduction to modeling
6. Exploration of potential sources for Blue-X (1 – 6.x nm range)

Module 2: EUV Multilayers (Marcelo Ackermann , XUV Optics, UTwente) (1.5 Hours)

The course will cover the following topics:

- Multilayers coatings for short wavelengths
- Material selection vs wavelengths
- Theoretically achievable reflectivities and physical limits
- Interface engineering at the atomic scale: roughness, intermixing and compound formation
- Thin film deposition techniques for ML optics – key advantages and limitations

Module 3: Fundamentals and Applications of Coherent High Harmonic EUV Sources Henry C. Kapteyn (1.5 Hours)

Coherent EUV sources based on high-order harmonic generation have emerged as a useful tabletop-scale tool for science and technology. In this introduction, we will provide an overview of this field. Topics include:

- The basics of high harmonic generation (HHG)
  - How it works
  - Technical requirements
  - Optimizing flux from HHG sources
  - Wavelength scaling
- Unique characteristics of HHG radiation
  - Ultrashort pulses
  - Coherence
  - Control over polarization
  - Exotic states of light—orbital angular momentum, etc..
- The utility of HHG light sources for
  - Monitoring dynamic processes in molecular and nanoscale systems
  - Angle Resolved Photoemission spectroscopy for quantum materials studies
  - Studies of thermal and spin transport
  - Coherent diffractive imaging and scatterometry

Module 4: Laser-driven accelerators and coherent EUV and X-ray Sources (Bjorn Manuel Hegelich, *TAU Systems, Inc.*) (1.5 Hours)

This module will provide an overview of Laser-driven accelerators and coherent EUV and X-ray Sources in the following areas:

- Laser-plasma based particle and light sources: Overview
- Ultrahigh Intensity Laser Technology
- Coherent EUV and Soft X-ray Sources from High Harmonic Generation
- Laser Wakefield Acceleration
- EUVX Free Electron Lasers
- Laser-driven Free Electron Lasers
- Coherent Source Technology status and outlook

Instructor's Bio

Gerry O'Sullivan

Gerry O'Sullivan obtained his B. Sc. in Experimental Physics in 1975 from University College Dublin where he subsequently completed his PhD in atomic spectroscopy under the supervision of Prof. Kevin Carroll in 1980. After brief periods at NIST, the University of Maryland and a longer stint at Dublin City University, he returned to UCD as a lecturer in 1986 and was Head of the School of Physics from 2002 to 2008. He is currently a Professor and director of the Atomic and Laser Physics Research (Spectroscopy) Group. His research interests include spectroscopy of laser produced plasmas, spectroscopy of ion gas collisions and the development of laser produced plasma based light sources for applications ranging from ionic photoabsorption studies to lithography and 'water window' microscopy. For the source
development work his group have been involved in a number of very productive collaborations with both academic and industrial research groups in Ireland, the US, the Czech Republic, Germany, Italy, Poland, China and especially, Japan. For his contribution to research he was elected to Membership of the Royal Irish Academy in 2004. In 2018 he was presented with a Lifetime Achievement Award for his contribution to EUV source development by EUV Litho
Inc.

Marcelo Ackermann

Marcelo Ackermann is chair of the Industry Focus Group – X-ray and EUV (XUV) optics at the MESA+ institute of the University of Twente. He obtained his PhD in physics (cum laude) in 2007 on a shared research project between Leiden University and the ESRF in Grenoble, under the guidance of Prof. Frenken and Prof. Ferrer. After that he held different leading positions in industrial research for the development of X-ray, visible and IR optics at cosine Research, Helbling Technik, SCHOTT Advanced Optics and ASML. In 2020 he re-joined academia as full professor in the XUV group, focusing on the development of next generation reflective, refractive and transparent X-ray and EUV optics in collaboration with industrial partners like Zeiss, ASML and Malvern Panalytical.

Henry C. Kapteyn

Henry C. Kapteyn is CTO of Kapteyn-Murnane Laboratories Inc. (KMLabs), a Professor of Physics and ECE at the University of Colorado at Boulder, and a fellow of JILA—a research institute joint between the University of Colorado and NIST. He and his wife and long-term collaborator, Margaret Murnane, are well known for their research in femtosecond lasers, and for understanding how to coherently upconvert this light to make a "tabletop x-ray laser" that generates ultrashort bursts of short-wavelength light. In recent years, they have applied this source to pioneering studies of atomic, molecular, and material studies at short length- and time-scales. He has published several hundred papers in topics ranging from laser science and engineering to materials to nanoimaging. He was elected to the US National Academy of Sciences in 2013, the American Academy of Arts and Sciences in 2018, and is a fellow of the American Physical Society, the Optical Society of America, and the American Association for the Advancement of Science. His awards include the Adolph Lomb Medal of the OSA in 1993, the Ahmed Zewail Award of the ACS in 2009, the R.W. Wood Prize of the OSA in 2010, the Arthur Schawlow Prize of the APS in 2010, and the Willis Lamb Award in Quantum Electronics in 2012, and the 2021 Benjamin Franklin Medal in Physics.

Bjorn Manuel Hegelich

Prof. B. M. Hegelich is the founder and CEO of TAU Systems Inc., an Austin, TX based Deep Tech company, developing and commercializing laser-driver particle accelerators and EUV/x-ray light sources for semiconductor, battery and medical applications. He is a professor at the University of Texas at Austin, leading the research group for Relativistic Quantum Photonics and one of the pioneers of laser particle acceleration. His research includes advanced particle and x-ray sources, high power lasers, nuclear fusion, and quantum effects in intense fields. Dr. Hegelich led research groups Los Alamos National Laboratory, South Korea's Center for Relativistic Laser Science and was appointed Visiting Professor and Fellow at the Center for Advanced studies at the LMU München. Dr. Hegelich received his B.S. degrees from University of Siegen and Napier University Edinburgh, his M.S. degree from the University of Göttingen and his PhD from LMU München and the Max-Planck-Institute for Quantum Optics. His research groups hold the records for the highest ion and electron energies generated with a laser.