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 short course will be taught by Prof. Gerry O'Sullivan (University College Dublin), Prof. Ladislav Pína (Czech Technical University in Prague), Prof. Henry Kapteyn (KMLabs and University of Colorado at Boulder), Prof. Bjorn Manuel Hegelich (Tau Systems and University of Texas at Austin) and Dr. Dinh Nguyen (Xlight). Each of these five modules are 1.5 hours long.

Registration Link

www.euvlitho.com/shop

Course Material

Students will be mailed a copy of the textbook, 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) (1.5 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:

- Basic plasma properties and processes
- 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
- Optimization of emission from 13.5 nm and BEUV lithography sources
- Challenges for EUV and short wavelength operation, comparison of LPP and DPP sources.
- Brief introduction to modeling
- Exploration of potential sources for Blue-X (1 – 6.x nm range)

Module 2: Grazing Incidence Optics and Applications for EUV and Soft X-ray Sources (Ladislav Pína, Czech Technical University in Prague, Czech Republic) (1.5 Hours)

The course will cover the following topics:

- SXR/EUV sources (electron tubes, hot plasma, accelerators)
- Grazing-Incidence X-ray Optics (GIXO) Introduction
- Rotationally Symmetric GIXO (Parabolic, Ellipsoidal, and Wolter Mirrors) as Related to EUV and Soft X-ray Sources
- Design rules (source size, spectral range, magnification, geometry, materials, and limitations)
- Computer modelling (software for RE, RP, and RW design calculations and raytracing)
- Design and raytracing examples

- Manufacturing and metrology in optical and X-ray regions
- Lobster-Eye (LE) and Multi-foil Optics (MFO)
- LE and Kirkpatrick–Baez LE
- Design and raytracing examples
- Manufacturing and metrology in optical and X-ray regions (SXR/EUV imaging and detectors)

Module 3: Laser-driven accelerators and coherent EUV and X-ray Sources (Bjorn Manuel Hegelich, *TAU Systems, Inc. and UT Austin*) (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

Module 4: Fundamentals and Applications of Coherent High Harmonic EUV Sources Henry C. Kapteyn (K& M Lab and Univ. of Colorado, Boulder) (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 5: FEL for EUV Lithography
Dinh Nguyen (xLight) (1.5 Hours)

This short course will provide an overview of the underlying physics of a free-electron laser (FEL) driven by modern radio-frequency linear accelerators (RF linac). After completing the course, the attendees will be able to:

- Understand the basic process of tunable coherent monochromatic light generation in an EUV FEL
- Become familiar with different components of an RF linac and
- Be able to identify the FEL characteristics that are beneficial to EUV Lithography.

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.

Ladislav Pina

Ladislav Pína received M.Sc. and Ph.D. degrees from the Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, in 1972 and 1978, respectively. From 1980 to 1981, he was on a study stay at the Department of Pure and Applied Physics of the Queen's University of Belfast that included experimental work using ion and x-ray diagnostics of laser plasma at Rutherford Appleton Laboratory. In 1983, he joined the Department of Physical Electronics as Assistant Professor and has been teaching electricity and magnetism, quantum electronics, and x-ray physics ever since, and supervising M.Sc. and Ph.D. students. His research interests include physics of generation, detection, and imaging in the EUV to x-ray radiation bands. Prof. Pína is a member of SPIE.

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.

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.

Dinh Nguyen

Dinh Nguyen has been an FEL Senior Scientist at xLight, Inc. since March 2024. Prior to joining xLight, he was a Senior Scientist at SLAC and Los Alamos National Laboratories where he developed a number of electron beam and FEL technologies. Dinh Nguyen is a Fellow of the American Physical Society, a member of the International Free-Electron Laser Conference Executive Committee, and the recipient of the 2017 International FEL Prize. He has taught the US Particle Accelerator School Free-Electron Laser course several times, including the latest one in July 2024.