Could you begin with an overview of your research interests?

My present research efforts encompass two different yet complimentary areas – optical materials and their response to intense laser illumination, and the nanoscale resolution imaging applications of novel laser sources which emit at wavelengths at least 10 times smaller than blue light.

We have developed microscopes that can image nanostructures thousands of times smaller in diameter than a human hair. We have also developed a microscope able to map and image chemical composition at the nanoscale. Further to this, we are learning how materials interact with short wavelength extreme ultraviolet (EUV) and soft X-ray (SXR) light, and exploiting this interaction to engineer imaging systems.

What is the purpose of ion beam sputtering?

Our work on optical materials is focused on the engineering of interference coatings by ion beam sputtering. These are stacks of amorphous dielectric films, with a thickness of 150 nm or so. The ion beam sputtering process involves an energetic ion beam eroding the surface of a target, typically a metal. This creates a plume of atoms, molecules and clusters which are deposited onto a sample substrate.

Could you discuss this in greater detail?

EUV laser ablation is one of the most intriguing laser/material interaction processes. It involves the creation of plasma with unique characteristics, which depend on illumination, wavelength, pulse duration and on the material being ablated.

We use a reactive process to create amorphous metal-oxide thin films from a metal target. By selectively depositing different materials with pre-selective thickness, we are able to engineer multilayer thin film coatings with tailored optical properties. These coatings are used in the cavity of lasers and to direct laser light in optical systems.

We are investigating the optical and structural properties of these thin films, and how they can be modified by altering the conditions of deposition. This is providing insight into how to develop better materials which can survive in the different environments of the optical cavity of infrared and visible high power and high energy lasers.

Your group was the first to demonstrate EUV laser ablation of nanoscale structures. Could you discuss this in greater detail?

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We exploited the short wavelength of EUV laser illumination to ablate nanometre-scale craters in organic materials, using a single laser shot. We are now using EUV laser ablation to develop a new methodology for mass spectrometry imaging which, for the first time, is enabling 3D nanoscale composition mapping.

Can you give an insight into the importance of your collaborations with Colorado State University (CSU)?

In my research I have developed very important and strategic collaborations which feed and advance the research. Contributing to establishing a successful Engineering Research Center in Extreme Ultraviolet Science and Technology with colleagues at the University of Colorado, the University of California at Berkeley and Lawrence Berkeley Lab has been an extremely rewarding experience. My efforts in advancing optical materials have also benefited from fruitful collaborations with scientists at other academic institutions and at national labs. The
interactions with my collaborators at CSU, and other institutions, play an important role in the education of my graduate students.

You have said that there is nothing more stimulating than working with enthusiastic students and instilling the love for learning. What is your role in nurturing the next generation of scientists in your field?

Working with students is certainly one of the most stimulating aspects of being a professor. I contribute to training the next generation of scientists and engineers through my teachings in the classroom and in the research lab and through my work ethic. I have introduced several courses at CSU and in all of them I have included a laboratory component. This is because I consider the laboratory experience unique in that it provides students with the opportunity to blend concepts from coursework, to learn new skills, and to grow and excel by working on challenging and interesting problems. Working in the lab also allows students to collaborate with others. I have been fortunate to work with many talented students, in the classroom and in my research.

Have you any plans in the pipeline for the coming years?

To expand my research programme. This is my fuel. The projects I am working on presently are very exciting and there is still a lot to learn.

My professional life extends beyond the University. I am president of a small start-up company called XUV Lasers, which I plan to grow. I have extensive involvement with professional societies. I am the founding and present Editor-in-Chief of the IEEE Photonics Journal, the first Institute of Electrical and Electronic Engineers (IEEE) online journal, which is still evolving and there is plenty to do.

CARMEN MENONI is a Professor of Electrical and Computer Engineering at Colorado State University (CSU). As an internationally recognised researcher in optics, Menoni leads cutting-edge research in soft X-ray nanoscale microscopy and optical materials. Her induction as a Fellow of three leading professional societies in her field – the Institute of Electrical and Electronic Engineers (IEEE), the American Physical Society (APS) and the Optical Society of America (OSA) – is testament to her important scientific contributions. As the first female tenured professor in the 102-year history of her department, Menoni serves as an excellent role model for women in engineering.

Menoni’s research encompasses two different, yet complimentary, areas – optical materials and their response to intense illumination and nanoscale imaging with bright beams of soft X-ray laser light. “Our work on optical materials is relevant to the development of visible and infrared high power and kilo-Joule level lasers, as those used for laser fusion,” she explains. Understanding the interaction of intense illumination with the coatings in the laser cavity is critical to increase output power. Menoni’s research forms part of the worldwide effort to develop powerful optical lasers that have applications in the generation of secondary X-ray radiation, in laser-driven particle acceleration and inertial fusion.

RAPID PROGRESS

Trained as a solid-state physicist and spectroscopist, much of Menoni’s early work focused on the fundamental properties of semiconductor materials. Although it makes use of this background, her current research is significantly different.

Over the last 10 years Menoni has led active research in optical materials and soft X-ray imaging is pushing the frontiers of optics. Future work will present unique opportunities for the study of laser/material interactions and the possibility to demonstrate novel imaging tools.

CARMEN MENONI

Harnessing light with innovative optical technologies

At Colorado State University, pioneering research in optical materials and soft X-ray imaging is pushing the frontiers of optics. Future work will present unique opportunities for the study of laser/material interactions and the possibility to demonstrate novel imaging tools.

Menoni is also co-principal investigator (PI) of the National Science Foundation (NSF) Engineering Research Center (ERC) for Extreme Ultraviolet (EUV) science and technology with headquarters at CSU. In collaboration with other EUV ERC participants, her group has demonstrated novel imaging systems that use laser illumination with wavelengths 10-50 times shorter than blue light wavelengths to image morphology and monitor dynamics and chemical composition at the nanoscale, “Having access to these bright table-top laser sources of short wavelength light incentivised many of the research projects I am currently working on, and moreover is opening opportunities to develop compact systems with the potential for commercialisation,” Menoni reveals. The work at the EUV ERC has yielded the first compact EUV microscopes that can image nanoscale objects and observe nanoscale interactions. For this work Menoni and her team were awarded an R&D 100 Award. Colloquially known as the ‘Oscars of innovation’, these awards recognise the top 100 technology products of the year. Menoni’s group received the award for their invention
INTELLIGENCE
OPTICAL MATERIALS AND HIGH POWER LASERS AND EXTREME ULTRAVIOLET AND SOFT X-RAY PHOTONICS

OBJECTIVES
• To develop thin film multilayer structures by ion beam sputtering for interference coatings for high power lasers
• To exploit bright laser pulses that emit in the extreme ultraviolet and soft X-ray region of the electromagnetic spectrum to demonstrate novel imaging methods for applications in nanoscience and nanotechnology

KEY COLLABORATORS
Jorge J Rocca, Mario C Marconi; Elliot Bernstein; Patrick Nauleau; David Attwood; Erik Anderson; Margaret Murnane; Henry Kapteyn; Weilun Chao; Stephen Leone
Engineering Research Center for Extreme Ultraviolet (EUV) Science and Technology, Colorado, USA • Dean Crick; Dinesh Patel; Sandra Biedron, Colorado State University (CSU), USA • Wolfgang Rudolph, University of New Mexico (UNM), USA • Christopher Stolz, Lawrence Livermore National Laboratory (LLNL), USA • Alexander Vinogradov; Igor Artioukov, Lebedev Physical Institute, Moscow, Russia • Oscar Martinez, University of Buenos Aires, Argentina • Randall Urdahl, Agilent Labs • Mark Curtin, Boeing

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PROFESSOR CARMEN MENONI is an internationally recognised researcher in optics, a leader in the engineering profession and a role model for women in engineering and science. Her technical contributions have merited her election to Fellow of three of the leading professional societies in her field of expertise: the Institute of Electrical and Electronic Engineers (IEEE), the American Physical Society and the Optical Society of America. She has established strong research programmes at CSU in semiconductor physics, optical materials science and engineering, and nanoscale imaging.

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of a table-top microscope that uses extreme ultraviolet laser light to capture images with a single nanosecond flash.

RESEARCH ARMS
Menoni’s research is divided between two key themes: X-ray photonics; and optical materials, comprising laser/material interactions and interference coatings.

Her group’s primary focus in optical materials is on the development of amorphous dielectric films by ion beam sputtering, a deposition method that is used to engineer multilayer interference coatings for lasers. An interdisciplinary approach is essential to this work and there is a growing universality of this concept in modern research. “The problems we are trying to solve to advance the current state-of-the-art require an understanding of physics, materials science and chemistry. Our work is highly multidisciplinary, but this is research in the 21st Century,” Menoni explains.

Optical interference coatings are a well-developed technology and are ubiquitous in all lasers. Their design is based on elemental electromagnetic theory. Their behaviour under illumination from high average and high peak power lasers is to a certain extent unpredictable. Menoni hopes to understand the underlying physics controlling their laser damage behaviour. She is currently investigating the role of native defects in the performance of dielectric thin film coatings – a feature vital to improving their properties and optical response. Specifically, the team aims to ascertain whether deposition conditions can alter the density and distribution of native point defects, and in what way laser defects affect laser damage in thin films.

Menoni and her team are also using bright laser beams that emit at wavelengths between 10 and 50 nm for applications. Working with other Center participants, they have demonstrated novel nano-imaging and nano-patterning systems that have applications in nanoscience and nanotechnology. “New table-top soft X-ray lasers demonstrated at CSU are revealing exciting opportunities for the implementation of new methods and instruments with unique characteristics,” Menoni elaborates.

WORLD FIRSTS
The team has obtained promising results to date. Their coatings can withstand irradiances of around 10 MW/cm², without experiencing damage. They have also demonstrated superior performance in coatings for ultrashort pulse lasers that operate at cryo-temperatures.

Menoni has pioneered the use of SXR laser ablation of nanoscale structures, taking advantage of the ability to focus the laser beam to 100 nm diameter. In collaboration with microbiologists and chemists, the team has demonstrated three dimensional chemical composition imaging at the nanoscale by SXR laser ablation mass spectrometry.

FUTURE GOALS
Looking to the future, Menoni plans to expand her research by seeking new applications for her imaging work in material science and biology. She also has concrete plans to extend her research in optical thin films coatings to other wavelengths. Results obtained thus far have been promising.

Menoni will continue to feed her passion for teaching and mentoring by recruiting talented students that are excited about engineering and by ensuring that they develop the skills necessary for success in industry and academia. At CSU, she leads an active international research programme that has attracted undergraduate research scholars and graduate students from all over the US, Spain, Germany, Russia, the Czech Republic, France and Argentina.