Deep Ultraviolet Free Electron Laser Reaches New Milestone Using BNL's Unique HGHG Process

November 1, 2002 - After three years of intense effort in developing a new source of laser light called a deep ultra-violet free electron laser (DUV-FEL), BNL scientists generated very intense ultraviolet light by a process called high gain harmonic generation (HGHG). This process, unique to BNL, was developed under the direction of Li-Hua Yu, a physicist at the NSLS. HGHG will ultimately generate deep ultraviolet laser light with unsurpassed brightness.

"Such intense light," Yu says," will be a powerful new tool that will reveal fine details of atomic interactions inside materials and the very fast motions of molecules in chemical reactions all this with a precision unequaled so far."

By using the HGHG process, the DUV-FEL seeks to achieve very short wavelengths of light. While visible light's wavelengths range from 400 nanometers (nm) for blue light to 700 nm for red light - a nanometer being a billionth of a meter - the wavelength of the light produced at the DUV-FEL last week was 266 nm. The HGHG process also generated significant deep ultraviolet light at 88 nm.

The advantages of two current light sources will be combined in the DUV-FEL. By generating very intense deep ultraviolet light, the DUV-FEL will act like a synchrotron, which delivers short wavelengths but less intense light, and a laser, which produces very intense light, but only at longer wavelengths.

Over the last three years, the DUV-FEL has been advancing through many steps, each step representing a new technological challenge. The many NSLS scientists, engineers, and technicians who made key contributions to overcome these challenges include physicists William Graves, Erik Johnson, Samuel Krinsky, Timur Shaftan, and Brian Sheehy; postdoctoral research associates Adnan Doyuran and Henrik Loos, mechanical engineer John Skaritka, and radio frequency engineer Jim Rose. The experiment also benefited greatly from the scientific contributions of Ilan Ben-Zvi, Richard Heese, George Rakowsky, Xijie Wang, and Zilu Wu; the computer control of Kate Berman; and the technical assistance of Joseph Greco, Dave Harder, Michael Lehecka, Phil Marino and Boyzie Singh.

"In addition," says Yu, "valuable contributions were made by other scientists in past stages of the DUV-FEL. The team spirit of all who have worked on the project helped in achieving the present milestone."

Yu explains that the DUV-FEL can produce such intense light because of a property called "coherence." In both a synchrotron and an FEL, electrons are accelerated to near the speed of light, and then are forced to emit very intense light by going through magnets that bend their trajectories. But while light is emitted at random, or "incoherently," in a synchrotron, it is produced "coherently," in the DUV-FEL, leading to a dramatic increase in intensity, which can be up to 10 million times as intense as current synchrotron light.

"It is as if, instead of having a group of people singing the same song at different times, they sang in unison," says Shaftan.

Interim Lab Director Peter Paul (right) celebrates the latest milestone at BNL's DUV-FEL with National Synchrotron Light Source (NSLS) Department members (foreground, from left) Li Hua Yu, James Murphy, Adnan Doyuran, NSLS Chair Steve Dierker; (back, from left) Timur Shaftan, John Skaritka, Boyzie Singh, Erik Johnson, Henrik Loos, and Brian Sheehy.

In the DUV-FEL, the electrons can "sing in unison" in two different ways, called self-amplified spontaneous emission (SASE) and HGHG. In the first process, electrons interact with light emitted by their fellow electrons, creating small groups of electrons. "Inside each group, all the electrons sing in unison, but the songs between two groups are out of sync," Shaftan says.

In the HGHG process, the electrons interact with light provided by a laser at the entrance of the DUV-FEL, a process leading to groups of electrons, as before, but "this time, not only do you have a united choir in each group, but all groups sing together," Loos says. "This 'super-choir' of electrons generates light that is many times more intense than the one generated by the SASE process."

While many FELs are currently under development throughout the world, they are all based on the SASE process. Brookhaven's DUV-FEL is the only FEL using the HGHG process, which will allow it to generate the brightest deep ultraviolet light so far. Unlike SASE, HGHG also generates light at wavelengths that are fractions (one-half, one-third, one-quarter, etc.) of the input wavelength.

"Such harmonics can be generated by conventional lasers when they cross a given crystal or gas," Doyuran says. "But the intensity of these harmonics is much weaker than the input light. The big advantage of HGHG is that the harmonics are much more intense than those produced with a conventional laser."

To benefit from this very intense light, three BNL scientists from the Chemistry Department have already submitted proposals to use the DUV-FEL.

Arthur Suits is interested in using light-induced dissociation of atoms in hydrocarbons to reveal details of their molecular structure and bonding. "The DUV-FEL is really ideal for our experiments," he says. "The information we hope to gain using it would be impossible to obtain by other means."

Louis DiMauro plans to use the DUV-FEL's short and highly intense light pulses to study the interaction of matter with intense, short-wavelength light. "This tool will open up many new areas of research in fundamental and applied science," he says.

Michael White intends to use the DUV-FEL to study chemical reactions that occur on the surfaces of materials, for which the product yields are low or where the gaseous products are particularly difficult to detect.

Says White, "In the long term, the DUV-FEL will produce very short pulses that will provide new information on surface processes in real time."

For Yu and his collaborators, these proposals are a clear sign that the efforts of the past three years are coming to fruition.

"The scientific use of the DUV-FEL will be the best reward for all of us and the crowning of a lot of hard work and dedication from the scientists, engineers and technicians who worked on this project," says James Murphy, NSLS Associate Chairman for Accelerators.

-Patrice Pages

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The National Synchrotron Light Source Department team working on BNL's deep ultraviolet free electron laser include: (front, from left) Timur Shaftan, Richard Heese, Boyzie Singh, Adnan Doyuran, Phil Marino, and Li Hua Yu; (middle, from left) Joe Greco, James Murphy, Xijie Wang, Bill Bambina, Sorin Pop, Brian Sheehy, Zilu Wu, and James Rose; (back, from left) Henrik Loos, Erik Johnson, and John Skaritka.