A Franco-Japanese team demonstrates a new free-electron laser (FEL) concept experimentally

A Franco-Japanese team has succeeded in producing intense, coherent radiation in the extreme ultra-violet domain. This result validates the concept developed for the 'Arc-en-Ciel' project, a fourth-generation light source thought of by the French synchrotron radiation teams.

In 2003, French teams (CEA and SOLEIL) and Japanese teams (SCSS - SPring-8) decided to demonstrate that the free-electron laser concept, the basis of the French Arc-en-Ciel project, can provide a higher-performance, more compact light source, which is less costly and is complementary to the free-electron lasers developed until now. This was achieved, in that extreme ultra-violet light (from 160 to 30 nm) was produced. The medium-term aim is to obtain equally good results for shorter wavelengths, in the soft x-ray domain, which is especially suited to biology experiments.

Laser light sources from particle accelerators

FELs are light sources based on electron accelerators that produce very bright, very short flashes of light (of the order of ten femtoseconds), with similar properties to laser light (with respect to coherence, in particular).
Several FEL projects are currently under development all over the world. They are based on self-amplified light emission, in which high-energy electrons produced by an accelerator interact with the radiation they emit when their trajectory is made to oscillate in magnetic devices called undulators. These are called SASE (self-amplified spontaneous emission), and they exist particularly in Germany (FLASH) and in Japan (SCSS accelerator prototype).

An innovative concept developed for the Arc-en-Ciel project

The Arc-en-Ciel project is based on a different concept: it seeks to increase the spectral and temporal qualities of the light beam produced, whilst reducing the size of the machine, by replacing self-amplification with amplification induced by external radiation. Generated by a titanium-sapphire laser focused in a cell of noble gas, an extreme UV beam is selected, focused and injected in the FEL, where it interacts with the electron beams from the accelerator and groups them into very small bunches. These electron bunches then emit coherent radiation in phase, with the same maximum wavelength as the initial incident beam, and with a much higher intensity (x2600), which is also higher than that of the radiation obtained with a 'classic' SASE.

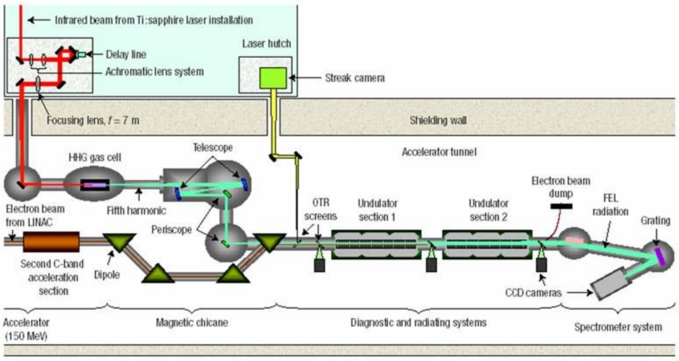
Soon, the 'water window' for chemists and biologists

There is a particular energy domain which is interesting for the study of complex organic samples: the 'water window' (in the region of 4 nm, i.e. 280 eV). The next experimental phase to be carried out by the teams of Marie-Emmanuelle Couprie at SOLEIL and Toru Hara of SCSS at SPring-8 will consist of using the same laser/gas cell to generate a 60 nm injection beam (instead of 160 nm in the current experiment) and to inject it into a series of undulators which will allow the packets of electrons to produce very intense soft x-rays with an energy close to that of the 'water window'.

Fourth-generation sources?

Developments like this demonstrate the interest of these new light sources, even though they will be expensive to produce in view of the number of experimental installations the FELs will offer to users. Note that a synchrotron, on the other hand, allows dozens of experiments to be carried out at the same time, over a wide range of wavelengths and for almost all scientific and industrial communities. This aspect was taken into account in the Arc-en-Ciel project, which is planned ultimately to include up to 11 experimental installations.

FELs represent great potential for research and scientific breakthroughs which, particularly in the context of Arc-en-Ciel, encourage international collaborations and a very fruitful spirit of competition.



Layout of the experiment. *A Ti:sapphire laser (800 nm, 20 mJ, 100 fs FWHM, 10 Hz) is loosely focused into a xenon gas cell (focal length f =7 m), optimizing HHG output. Using the telescope and periscope optics (CaF2 mirrors), the HHG seed beam is spectrally selected, refocused and spatially and temporally overlapped with the electron beam (150 MeV, 1 ps FWHM, 10 Hz—LINAC stands for linear accelerator) in the two consecutive undulator sections 1 and 2, which are both tuned to 160 nm, corresponding to the fifth harmonic of the laser. The beam position is monitored on optical transition radiation (OTR) screens.*

Related articles

Injection of harmonics generated in gas in a free-electron laser providing intense and coherent extreme-ultraviolet light. *On line in Nature Physics, 9 March 2008.*
http://www.nature.com/nphys/journal/vaop/ncurrent/full/nphys889.html

Free-electron laser benefits from 'seed' light. *On line in Physics World, 12 March 2008.*
http://physicsworld.com/cws/home

Free-electron laser to probe cell behaviour. *On line in nanotechweb, 14 March 2008.*
http://nanotechweb.org

ARC-EN-CIEL website: http://arcenciel.synchrotron.fr/ArcEnCiel

NOTE

Located on the Saclay Plateau, in Essonne, SOLEIL is the French national synchrotron facility. It is both a major multidisciplinary instrument and a research laboratory. SOLEIL is a civil law partnership whose two shareholders are the CNRS and the CEA, and in which the Ile-de-France Region and the General Council of the Essonne have also invested a great deal.

SOLEIL is an electron accelerator which produces exceptionally bright light covering a very wide range of wavelengths, from infra-red to x-ray, and including ultra-violet. The characteristics of this light (intensity, focus, stability, polarisation, etc.) make it possible to observe matter down to the atomic level, and allow experiments to be carried out in such diverse areas as biology, physics, the environment, materials science, and archaeology, both in fundamental research and applied or industrially-relevant research.

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