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Feasibility Study of X-ray Free Electron Lasers in Fourth Generation Storage Rings

Particle accelerators can create electron beams moving at almost the speed of light. These electron beams have enough energy that they produce light we can exploit for scientific experiments. Just how X-rays are used to look inside the human body, scientists use this light to investigate materials or organisms of all kinds. When an electron beam is forced to *undulate*, i.e. move along a zig-zag path, it emits light. The periodic magnets used to cause this wavy movement are called undulators, and depending the size and strengths of these magnets, different wavelengths of light can be produced. In experiments where the light is used, smaller wavelengths mean the ability to resolve smaller structures. Very short wavelengths are referred to as X-rays.

Free electron lasers (FELs) are one type of machine used to produce light using electron beams and undulators. They consist of undulators in which the electron beam interacts with the light emitted in order to stimulate even brighter light pulses, which are ideal for scientific experiments. The interaction between light and electron beam takes a lot of distance. This leads to two different FEL set ups. FELs can either be linear structures, which are long enough to facilitate this interaction, or they can be inserted into storage rings. Storage rings are large circular machines, in which electron beams circulate. As the undulators have to be straight, storage ring FELs are inserted into linear parts of the "ring".

To give enough distance for the electron-light interaction, storage ring FELs use *optical cavities*. In the cavities the produced light is reflected back into the undulator, and the interaction takes place through several passes. Until recently there were no mirrors that could reflect X-ray light well enough, so that X-ray storage ring FELs were not feasible. However X-ray mirrors have greatly advanced in recent years, with diamond crystals showing more than 99 % reflectivity. However this reflectivity is restricted within a very narrow bandwidth.

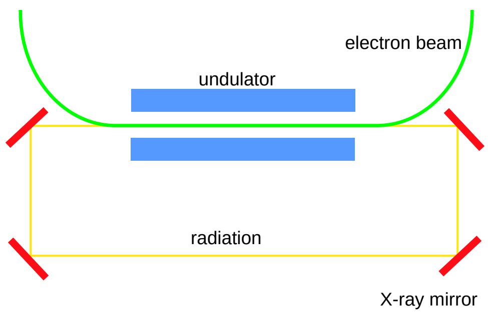

Figure 1: Sketch of a cavity based FEL

This research studies whether a cavity designed with these diamond mirrors could be part of a functioning X-ray FEL for storage rings. This is done by simulating a FEL set up producing X-ray radiation, based on the electron beam at the PETRA IV facility. PETRA IV is a planned upgrade of the PETRA III storage ring in Hamburg, Germany. The effects of the mirrors on the produced radiation is then modelled, and the feasibility evaluated.

It is shown that the X-ray cavity losses are low enough to enable the interaction between electron beam and radiation necessary for the amplification of light production.This means that in the future cavity based X-ray free electron lasers could be inserted into storage rings, allowing for more experiments relying on bright X-ray pulses.

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