DESY Summer Student Programme 2009

Project report

"Adventure at FLASH"

supervisor: Prof. Henry Chapman

Karol Nass

AGH University of Science and Thechnology

Faculty of Physics and Applied Computer Science

September 9, 2009

Abstract

On a lovely summer 2009 within the days from 21st of July to 10th of September one Polish guy named Karol Nass was a participant of The DESY Summer Student Programme. The intership took place in Hamburg, Germany in the Deutsches Elektronen-Synchrotron which is a Research Centre of the Helmholtz Association. Luckily he was one of the 76 students from all around the world admitted for this intership. He was very happy to have very interesting project. More about it you can read in next pages.

Contents

1 Introduction

The DESY Summer Student Programe 2009 was held in Hamburg in the Deutsches Elektronen-Synchrotron which is a Research Centre of the Helmholtz Association. This year 76 students from different countries came to DESY to participate in lectures given by the DESY scientist and to work on individual projects given by theirs supervisors.

I was one of them. I am a fifth year student of AGH University of Science and Technology in Krakow, Poland. My specialisation is Medical Physics and Dosimetry.

Prof. Henry Chapman from the CFEL group was my supervisor, together with him and the others from his group we were working on FLASH experiments and sample preparation for FLASH experiments.

Project name “Adventure on FLASH” was given by me because it is the most suitable name for the work I did during these unforgettable holidays at DESY. Together with my supervisor and his colleagues from CFEL group we were working on the most interesting experiments I did so far. Our work took place in the FLASH Experimental Hall, Sample Preparation Laboratory and in the office. I was acquainted with the work from all the steps of scientific work at the free electron laser. Starting from sample preparation, throughout experiment handling, ending with experimental data analysis.

My primary task was to learn as much as I could during this exciting time at the prototype of XFEL. I think this objective was completed and a lot of excellent knowledge was captured by me.

The European X-Ray Free Electron Laser (XFEL) facilities will be built in

2009 near DESY, Hamburg Germany, to be operational in 2013. Now a prototype of it, FLASH, is being investigated. XFEL is expected to have a strong impact in a wide range of scientific domains synchrotron radiation facilities because it will generate extremely brilliant and ultra short pulse of spatially coherent X-ray.

Figure 1: FLASH at DESY.

2 Free Electron Laser

More than 40 years ago the first coherent red light has been generated by a ruby laser. From that time an impressive scientific and technological development transformed a laboratory experiment in a pervasive device, widely utilized in all field of science and technique and in everyday life. More than 20 years ago the first coherent infrared light has been generated by a quite exotic new laser developed at the Stanford University (USA), this laser was named FREE ELECTRON LASER (FEL).

This new type of coherent radiation source appeared from the very beginning to be quite promising. The reasons of this fact lies on its operating principles. In a FEL the active medium is not made of atoms or molecules, it consists of a beam of free electrons, propagating at relativistic velocities in a spatially periodic magnet (undulator), where the electrons experience the Lorentz force, execute transverse oscillations and emit synchrotron radiation in the forward direction. The wavelength λ of the emitted radiation depends on the electron energy E, on the period of the undulator magnet λ_u and on its magnetic field B.

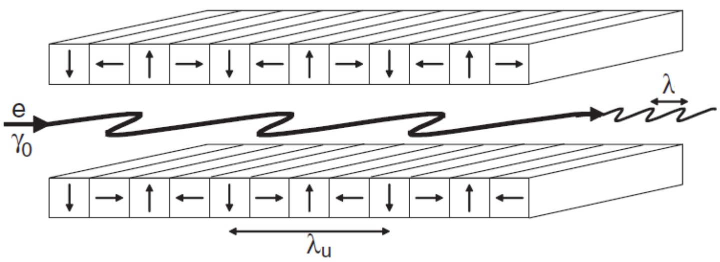

Figure 2: A wiggling electron in a planar undulator emits coherent radiation.

2.1 FLASH

FLASH (”F”reie-Elektronen-”LAS”er in ”H”amburg) is a prototype of the XFEL machine (X-ray Free Electron Laser). FLASH produces laser light pulses of short wavelengths from the extreme ultraviolet down to soft X-rays. Principal parts of FLASH are RF gun, bunch compressor lines, accelerating structures, collimator, undulator and FEL Diagnostics.

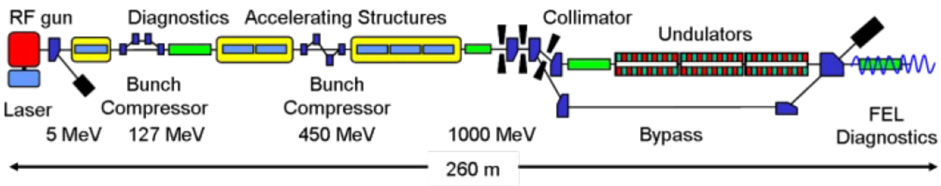

Figure 3: Schematic structure of the FLASH (not in scale).

While it is true that synchrotron radiation sources also deliver tightly collimated radiation, FLASH generates light with real laser properties, i.e. which is perfectly collimated. In the X-ray range, conventional lasers can only deliver low-intensity beams. In contrast, the peak luminosity of the FLASH radiation is several orders of magnitude higher, even than that of the most advanced synchrotron radiation sources. In addition, since the laser radiation from FLASH is emitted in ultra-short flashes, it provides the researchers using the new DESY facility with experimental capabilities not available from any other radiation source on the globe.

3 Sample Preparation

Before any experiment could be performed at the Flash beamline an adequate sample must be prepared. That was my first task to accomplish. I needed to prepare a sample which could be later investigated with short x-ray pulses from the FLASH laser. However this was my firs task, it accompanied me to the end of the summer school.

3.1 Focused Ion Beam (FIB)

In the sample preparation laboratory I have been acquainted with the sample production method by Miriam Barthelmess. To prepare the FLASH sample we needed to use Focused Ion Beam apparatus combined with the Scanning Electron Microscope. Samples were created on the 30 nm thick Si_3N_4 + 70 nm thick Tungsten membrane.

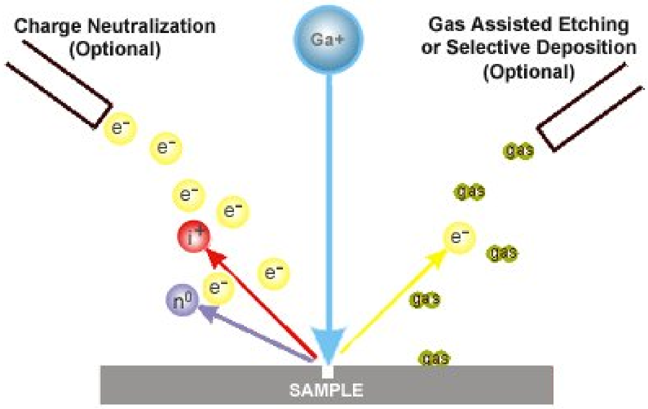

Figure 4: The principle of FIB.

FIB systems use a focused beam of gallium ions that can be operated at low beam currents for imaging or high beam currents for site specific sputtering or milling. As the figure above shows, the gallium (Ga+) primary ion beam hits the sample surface and sputters a small amount of material, which leaves the surface as either secondary ions (i+ or i-) or neutral atoms (n0). The primary beam also produces secondary electrons (e-). As the primary beam rasters on the sample surface, the signal from the sputtered ions or secondary electrons is collected to form an image.

If the sample is non-conductive, a low energy electron flood gun can be used to provide charge neutralization. In this manner, by imaging with positive secondary ions using the positive primary ion beam, even highly insulating samples may be imaged and milled without a conducting surface coating.

3.2 Scanning Electron Microscope (SEM)

The scanning electron microscope (SEM) is a type of electron microscope that images the sample surface by scanning it with a high-energy beam of electrons in a raster scan pattern. The electrons interact with the atoms that make up the sample producing signals that contain information about the sample's surface topography, composition and other properties.

The types of signals produced by an SEM include secondary electrons, backscattered electrons, characteristic x-rays, light (cathodoluminescence), specimen current and transmitted electrons. Secondary electron detectors are common in all SEMs. The signals result from interactions of the electron beam with atoms at or near the surface of the sample. In the most common or standard detection mode, secondary electron imaging or SEI, the SEM can produce very high-resolution images of a sample surface, revealing details about less than 1 to 5 nm in size.

A beam of electrons is produced at the top of the microscope by an electron gun. The electron beam follows a vertical path through the microscope, which is held within a vacuum. The beam travels through electromagnetic fields and lenses, which focus the beam down toward the sample. Once the beam hits the sample, electrons and X-rays are ejected from the sample. Detectors collect these X-rays, backscattered electrons, and secondary electrons and convert them into a signal that is sent to a screen similar to a television screen. This produces the finalimage.

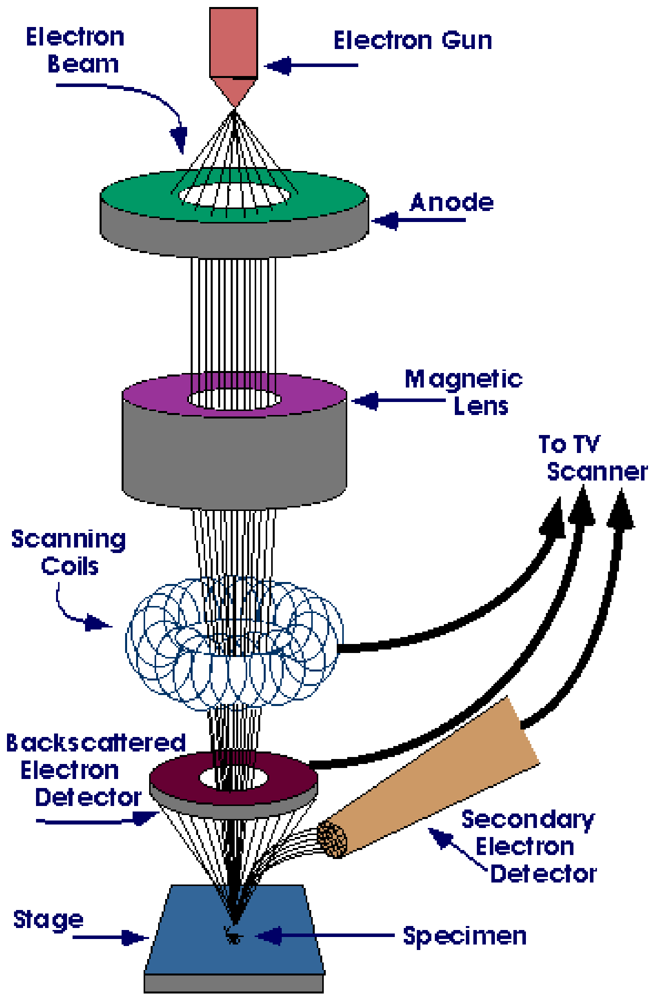

Figure 5: The SEM diagram.

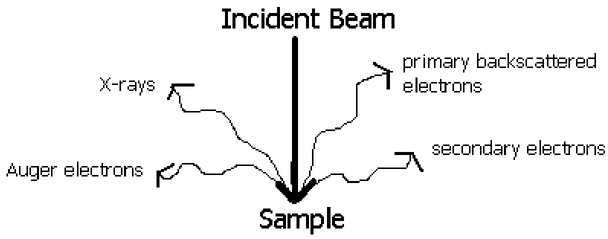

Figure 6: Ejected products of the beam hitting a sample.

4 Samples

4.1 Sample FLASH-2009-08

Three different kinds of samples were prepared with the FIB. Working names of them are: molecule, gold, gold and molecule. Patterns were milled on the 300nm Si3N4 + 70nm Tungsten substrate. Below pictures taken by SEM.

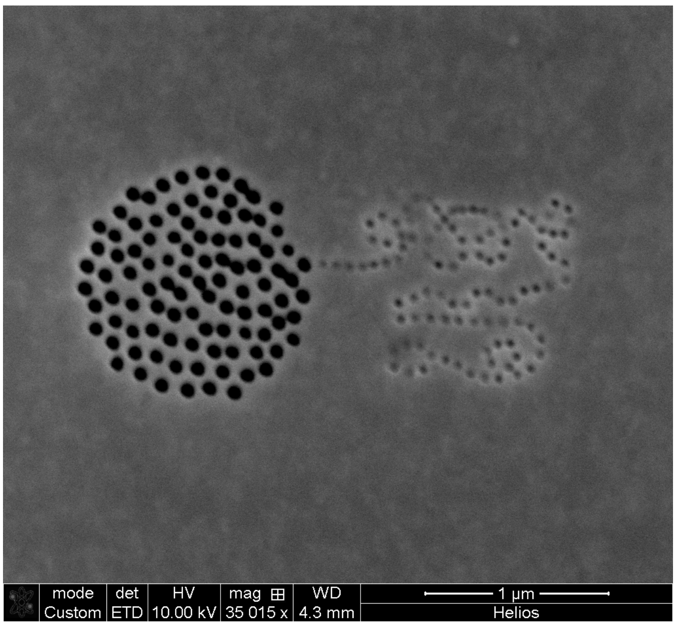

Figure 7: FLASH-2009-08 "Gold and molecule" pattern

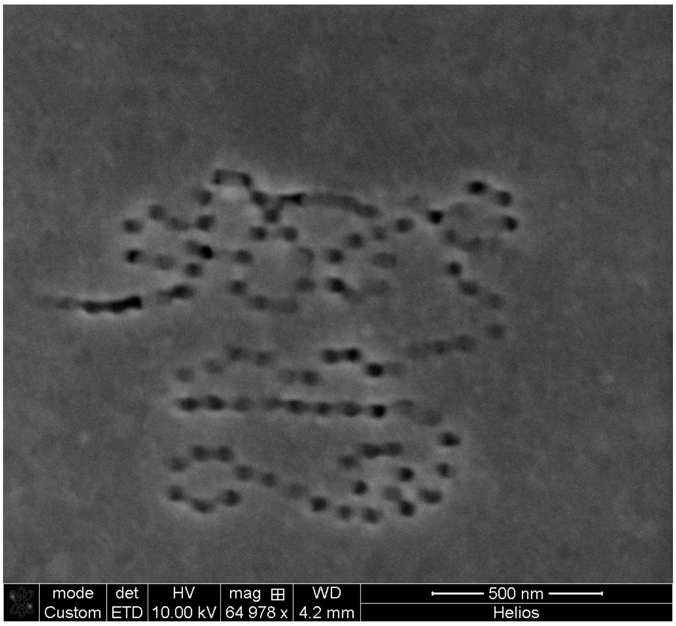

Figure 8: FLASH-2009-08 "Molecule" pattern

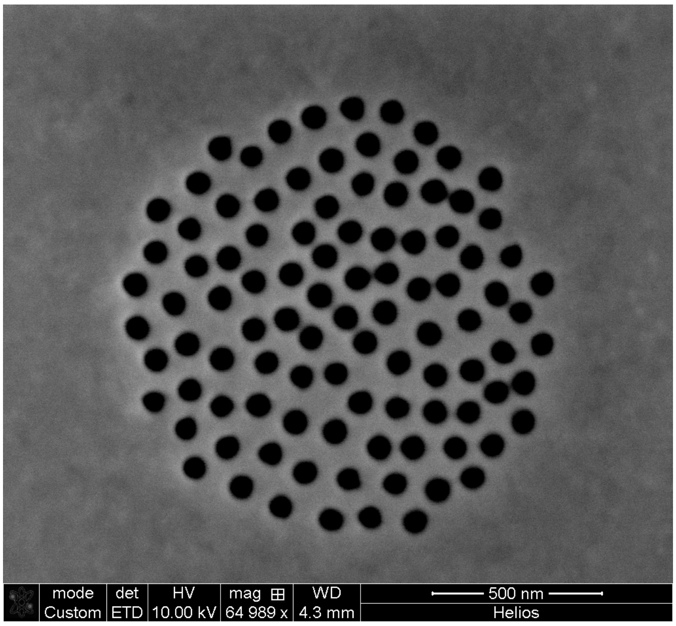

Figure 9: FLASH-2009-08 "Gold" pattern

5 Experiments

Coherent diffractive imaging is an ideal method for high-resolution ultrafast imaging with an FEL. Since no optical element is required, the method can in principle be scaled to atomic resolution with short enough wavelength. Spatial and temporal coherence are necessary to ensure that the scattered light waves from all positions across the sample are correlated when they interfere at the detector, giving rise to a coherent diffraction pattern that can be phased and inverted to give a high-resolution image of the sample.

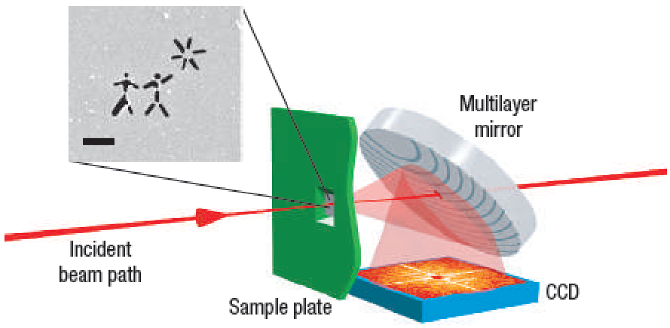

Figure 10: Schematic diagram of the experimental apparatus.

Demonstration of X-ray signal amplification phenomena with strong reference wave from the gold particle. Diffraction experiments at FLASH were performed with different kinds of samples (listed in the "Samples" section). Diffraction patterns were obtained.

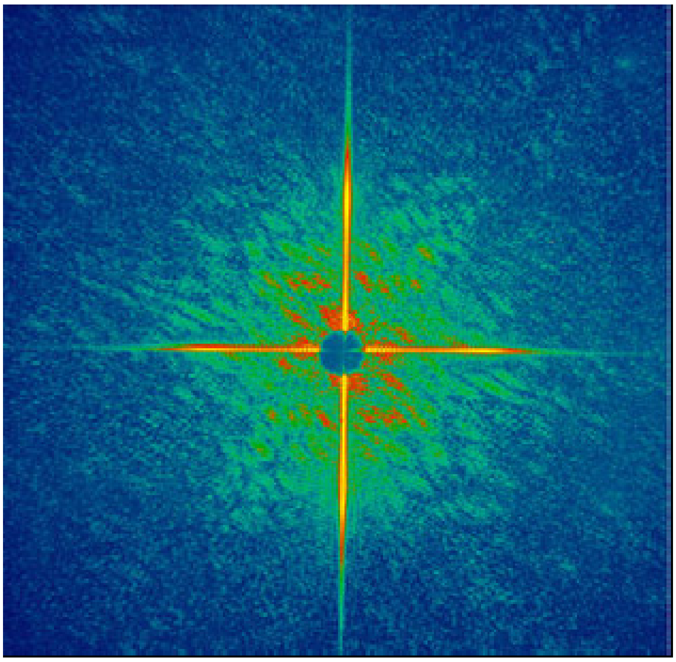

Figure 11: Flash X-ray coherent diffraction pattern.

6 Conclusions

These results have implications for studying non-periodic molecular structures in biology, or in any other area of science and technology where structural information with high spatial and temporal resolution is valuable. They also point to the viability of nanometre- to atomicresolution imaging

7 Acknowledgements

I wish to thank all the people who made completion of project possible. My deepest appreciation goes to my supervisor Prof. Henry Chapman for his valuable advice and their powerful encouragement throughout this research. I also would like to express my gratitude to Miriam Barthelmess and Mengning Liang for their patience, useful comments and excellent suggestions. I wish to sincerely express my appreciation to Prof. Dr. Jochim Meyer, Andrea Schrader and people who are behind the summer student program are also greatly acknowledged for this invaluable experience.