ESRF	**Experiment title:** Electrically detected X-ray absorption spectroscopy	**Experiment number**: HC-1940
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Report:

When a semiconductor absorbs a hard X-ray photon, the primary electron creates a cascade of several thousand conduction band electrons.[1] Although absorption of hard X-rays is an atomic process, the primary electron can travel many nanometres in the surrounding crystal.[1] Furthermore, the secondary conduction band electrons can travel several µm before recombining, and are sensitive to quantum confinement and surface effects. Therefore, nanostructured semiconductors could have vastly different response to X-ray absorption. We have previously shown that nanowires can have many orders of magnitude stronger X-ray induced current than expected from bulk parameters.[2] Understanding these processes is vital for X-ray detectors and to understand X-ray beam damage.

In this experiment, we have studied the X-ray beam induced conductance in single InP nanowires (NWs) from a solar cell device. The investigated NWs have a p-doped core and an n-doped shell, creating a core-shell diode.[3] The built-in electric field separates charge carriers generated by the sunlight, and this experiment investigated the electrical response by hard X-rays. Our original proposal was to make such measurements spectroscopically, with a tunable X-ray energy, but at the time of the experiment this was not possible while maintaining the nanofocus.

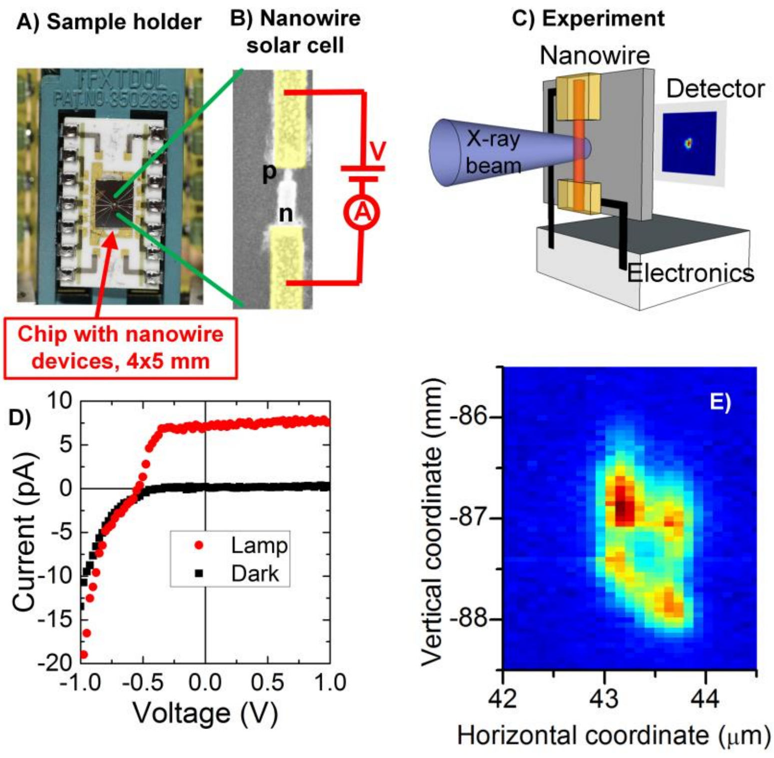

Fig. 1 *A) Sample holder with sample chip mounted. B) Electron microscope image of a nanowire device (not the one measured), with p- and n-segments. The gap between the contacts is 1 µm. C) Overview of experimental setup. D) I-V in dark and with lamp on. E) Map of the X-ray induced short-circuit current in the device, at 1.9% of the maximum flux. The maxium current is 5 pA.*

First, single-crystal InP NWs were put on a substrate chip, and individual NWs were contacted using electron beam lithography. The chip was then mounted on a chip carrier and contacted using wire bonding

(Fig. 1A-B). For the experiment, a custom-made sample holder with a socket for the chip carrier and contacts for electrical cables was also built. This allowed us to measure several different chips with the same sample holder. A bias voltage source and a picoampermeter were used for the electrical measurements. The sample holder was mounted on a plate with holes for the ID-01 piezo stage. Both the chip carrier as well the sample holder had holes drilled for collecting the scattered X-ray beam, but the scattered beam was not analyzed in this measurement. The X-ray experiments were performed at ID-01 (Fig. 1C). The 8 keV beam was focused using a FZP to 100 nm diameter.

First, we tested the electrical response in dark and with the microscope lamp on (Fig. 1D). The device showed a clear photocurrent with a short-circuit current (no bias voltage) of 8 pA, and a decent open-circuit voltage of 0.6 V. We avoided I-V scans with the X-ray on to minimize beam damage. Thereafter, we measured the spatial distribution of the short-circuit current by raster scanning the sample in the beam (Fig. 1E). The active region was large than expected, and showed four peaks. The reason for this is not understood. The maximum at this lowest flux was 5 pA.

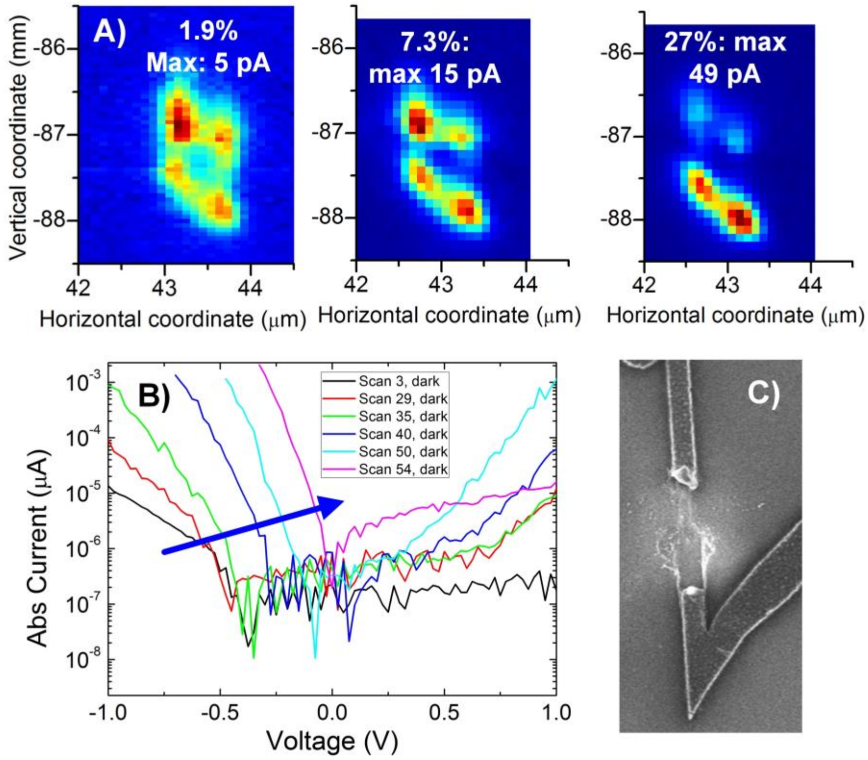

Fig. 2 *A) Maps of the X-ray induced current at different fluxes, measured as percent of the full flux. B) Dark I-V scans acquired during the experiment, after increasing fluxes in the mesh scans as in Fig. 1E. Absolute current, semilog plot. The arrow indicates the order of the scans. C) Electron microscopy image of device after measurements.*

We continued with similar scans at higher X-ray fluxes, which showed that the current increased approximately linearly with flux, while the spatial distribution changed (Fig. 2A). The smallest features observed were about 100 nm, similar to the focus size. After every spatial scan, we redid the dark I-V scan (Fig. 2B). The device showed increasing leakage at reverse bias, which indicates beam damage. After the beamtime, we checked the device in SEM and found that the nanowire was gone (Fig. 2C). This raises questions regarding the origin of the X-ray induced current. Further analysis is under way to understand the results. Note that in our previous investigations a NW device could sustain more than 24 hours of exposure to focused X-rays without permanent damage [2].

Clearly, beam damage is a major problem and lower fluxes should be used. However, it is encouraging that the X-ray induced current can be measured in a single nanowire p-n junction far below the maximum flux. The strong response also opens up for future energy-dependent measurements.

References

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