Conducting ion tracks in diamond-like carbon films

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The formation of ion tracks in diamond-like carbon (DLC) films on conducting Si substrates is studied. The films were produced by either conventional ion beam techniques (Univ. Göttingen) or by plasma deposition with magnetic filtering (filtered arc method, FhG Dresden). In both cases, the ions were implanted into the growing film with an energy in the order of 100 eV, thus creating by "subplantation" the conditions required for diamond formation. Such films are amorphous, contain 70-80% sp^3 bonds, and in the present case, have a thickness 40 and 100 nm, respectively.

The ion irradiation of the DLC films was performed at the UNILAC with Uranium projectiles of ~1GeV (moderated down from 2.7 GeV by Al foils). Due to the high energy deposition of the ions along their trajectories, the material is transformed from insulating diamond-like to conducting graphite-like carbon leading to thin electrically conducting channels embedded in an insulating matrix [1]. The properties of these channels were studied by means of scanning probe microscopy (AFM) using a conducting tip.

Figure 1 shows a three-dimensional AFM image of the surface topography of the irradiated DLC film. Hillocks with a few nm in height and ~20 nm in diameter are seen at the ion impact sites. The number of hillocks corresponds to the applied ion fluence.

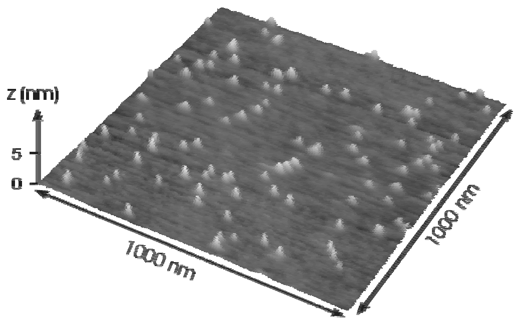

Fig.1 Topographical AFM image of a DLC film (FhG Dresden, 40 nm thick) irradiated with 10^{10} uranium ions per cm^2 of 1 GeV. The hillocks are due to the outflow of material at the ion impact site.

Figure 2 shows a three-dimensional plot of the current flowing between the AFM tip and the Si substrate through the DLC film. Each of the spikes corresponds to an ion track. Outside of the tracks the current is practically zero. Note, the current image originates from a different sample than the topographic image in figure 1.

The current between the substrate and the AFM tip as a function of voltage is presented in figure 3 for a spot on an ion-track and a spot outside of the track, indicating the overall noise level of the non-irradiated sample.

Assuming a track cross section of 100 nm^2, the measured current at 5 V gives a current density of 10^4 A/cm² and a electrical resistivity of ρ = 50 Ωcm. The conductance of the tracks is four orders of magnitude smaller than that of crystalline graphite, thus a very defective graphite filament is formed.

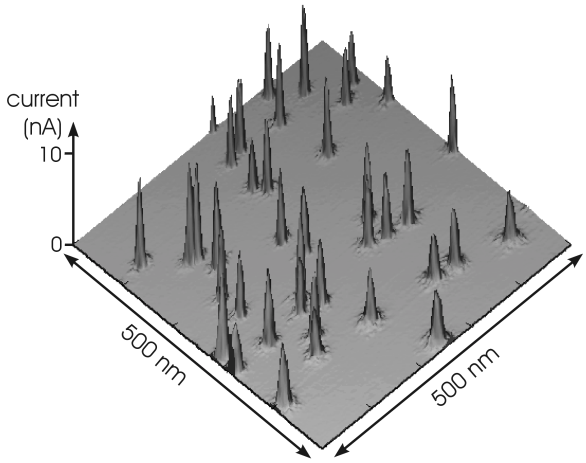

Fig.2 Current image of a DLC film (Univ. Göttingen, 100 nm thick) identically irradiated as sample of fig. 1. The current measurements were performed with a conducting AFM tip.

The general perspective of this kind of research is seen in the possibility to create nanostructures of materials which have properties distinctly different from the surrounding. In the present case, thin conducting filaments of graphite are embedded in an insulating diamond-like matrix. Such filaments may be useful in future mechanical or electrical nano-devices. A more immediate application is seen in the use of these tracks as electron field emitters in displays or other vacuum electronic devices (to replace hot filaments).

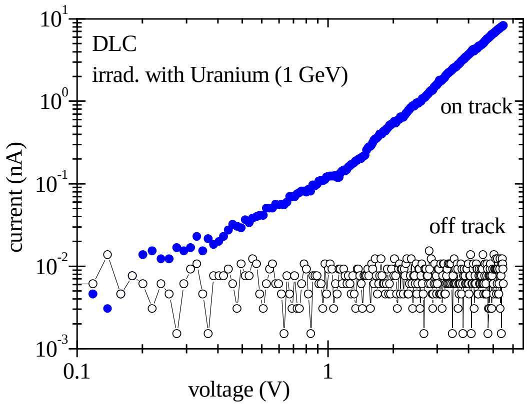

Fig.3 Current/voltage curve for a single ion track (AFM tip on top of a track). For comparison, the corresponding curve for the off track position is shown. DLC film from Univ. Göttingen, 100 nm thick.

[1] M. Waiblinger, Ch. Sommerhalter, B. Pietzak, J. Krauser, B. Mertesacker, M.Ch. Lux-Steiner, S. Klaumünzer, A. Weidinger, C. Ronning, H. Hofsäß, Appl. Phys. **A69** (1999) 239.