Self-aligned graphitic nanowires in diamond-like carbon

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Swift heavy ions are used to fabricate electrically conducting nanowires embedded in an insulating matrix. Starting material is an amorphous diamond-like carbon (DLC) film with a high fraction of sp^3-bonds (70 - 80 %) deposited on a conductive layer, e.g., highly-doped Si. The deceleration of the ions in the DLC film leads to a large energy deposition in a narrow region around the ion path, increasing the temperature to several thousand centigrade for a very short time (thermal spike). As a consequence, formally insulating diamond-like (sp^3) material is converted into graphitic (sp^2) carbon, forming a thin conductive channel with about 8 nm in diameter (verified by TEM measurements). Its length is determined by the film thickness which can vary from some nanometers up to several micrometers. The presence of the nanowires was confirmed by using atomic force microscopy (AFM) together with a conductive cantilever and an applied voltage between tip and Si-substrate (Fig 1).

Ion track formation described above is a single particle effect, i.e., each individual ion creates exactly one nanowire. This is different from other ion beam applications where usually a bundle of ions is used for structuring. The single ion method has the advantage that the structure diameter is smaller than achievable with focussed ion beams and that long straight structures can be created. With modern microbeam facilities, the ion tracks can be placed in an ordered array. This is important as it enables exact positioning, which is not possible for statistically distributed ions.

We present a technology that opens a new approach to active or passive self-aligned nanoscopic devices. Possible applications are field emitters (Fig 2) and other vacuum devices, quantum-based electronics or via interconnections in very-large-scale integrated circuits.

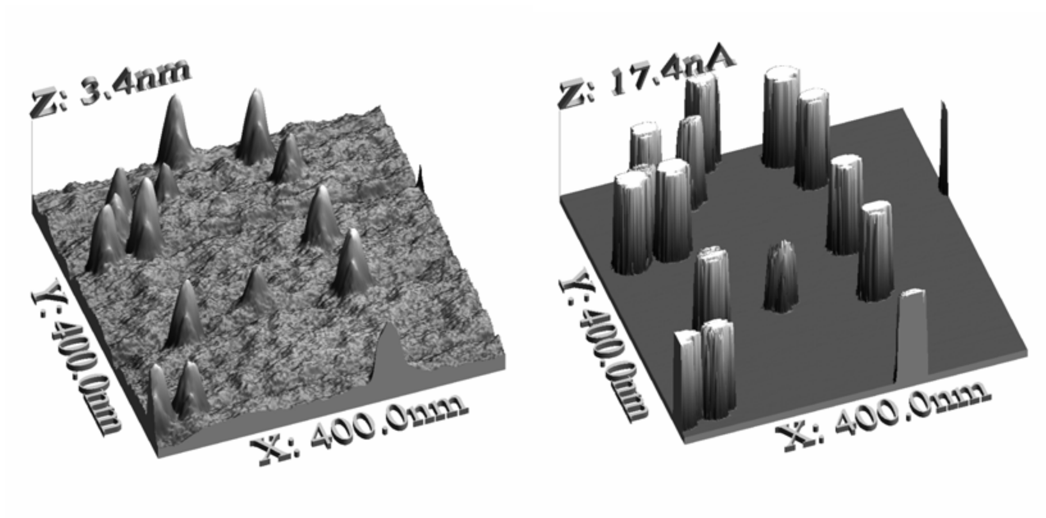

Fig 1: AFM images (400 nm x 400 nm) of surface topography (left) and current mapping (right) of a 50 nm thick diamond-like carbon film irradiated with 1 GeV U ions at a fluence of $1x10^{10}$ ions/cm^2. Data were recorded at the same time and show a one-to-one correlation between the hillocks, which mark the ion impact site, and the current peaks. Bias voltage between cantilever tip and Si-substrate was 50 mV, leading to a maximum current of 17,4 nA and thus to a current density of about 35.000 A/cm^2, providing 8 nm diameter of the single ion track.

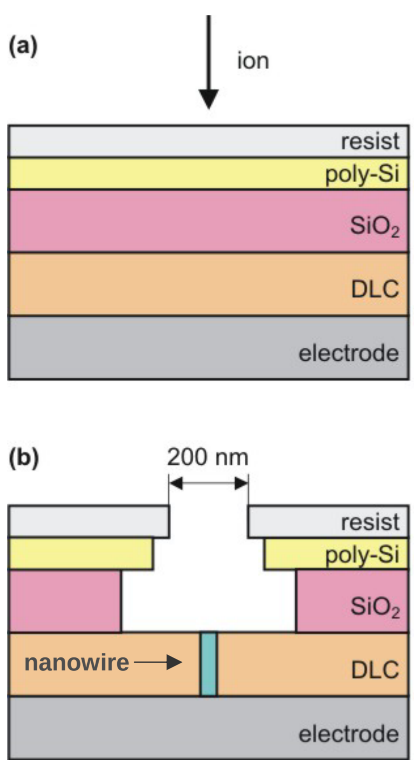

Fig 2: Production scheme for a gate electrode (highly-doped poly-Si) aligned with the conducting nanowire in DLC: A stack of layers of different materials with a resist (polycarbonate) as the top layer is irradiated with swift heavy ions (a). After opening the resist at the ion impacts, the layers beneath are etched in the now freely accessible region to create the structure shown in figure (b). Because of its compact rugged design (no free-standing parts), it is expected that such a structure could be useful in field emission or other vacuum devices.