FILMS CONSISTING OF GRAPHITE-LIKE SHEETS SUITABLE FOR INTERCONNECTS WITH HIGH ELECTRICAL AND THERMAL CONDUCTIVITY

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The graphite sheet is the strongest two-dimensional structure known and has high in-plane thermal and electrical conductivity. As a result, arrays of carbon nanotubes have been proposed as heat sinks and electrical interconnects [1]. Fully oriented sp^2 sheets [2] as described in this work are equally suited to these applications and as shown, they can be produced in a FCVA system with no requirement for high deposition temperatures or catalyst layers.

Carbon films with thicknesses in the range 20-80 nm were fabricated using a Filtered Cathodic Vacuum Arc (FCVA) deposition system and a sputtering system. By varying the substrate bias (in the FCVA only) as well as the background Ar gas pressure, films with different intrinsic stress were produced at room temperature. Following deposition, through-film I(V) characteristics were measured for each film. Figure 1 shows the normalised through-film resistance/nm (calculated at 1V) plotted against the intrinsic stress for sixteen carbon films. In the films deposited with low stress (1-5 GPa) asymmetric, current-voltage characteristics resembling those of a Schottky contact were observed (inset A) and the resistance-per-nm was of the order of 10^3 Ω/nm. In films with higher intrinsic stress (>7 GPa), ta-C was formed and while the non-linear behaviour was maintained, the resistance-per-nm exceeded 10^4 Ω/nm. In films deposited using a substrate bias of approximately 400 V (corresponding to an incident ion energy of approximately 300 eV) and with intrinsic stress of approximately 6 GPa, very different I(V) characteristics were observed. The high resistance non-linear current-voltage behaviour was replaced by a low resistance linear (Ohmic) current-voltage characteristic (inset B).

Figure 2(a) shows a cross-sectional bright field high resolution TEM image of a film with stress in the transition region located on the return path (dashed line) in Figure 1, where Ohmic behaviour was observed. The diffraction pattern (not shown) revealed localised graphitic {002} reflections aligned with the plane of the film and the microstructure consists entirely of graphite-like sheets aligned normal to the film surface. This orientation is preferred on the basis of energy minimisation of turbostratic graphite in a biaxial stress field. Films with this preferred orientation exhibit low resistance and Ohmic behaviour and are indicated by filled squares in Figure 1(a) on the dashed trajectory. Figure 2(b) shows how vertically aligned graphite-like sheets may be used in vertical interconnects.

References:

[1] P. Avouris, Z. Chen and V. Perebeinos, Nature Nanotechnology 2 (2007) 605
[2] D. W. M. Lau, D. G. McCulloch, M. B. Taylor, J. G. Partridge, N. A. Marks, D. R. McKenzie, E. Teo and B. K. Tay, Physical Review Letters 100 (2008) 176101

Figures:

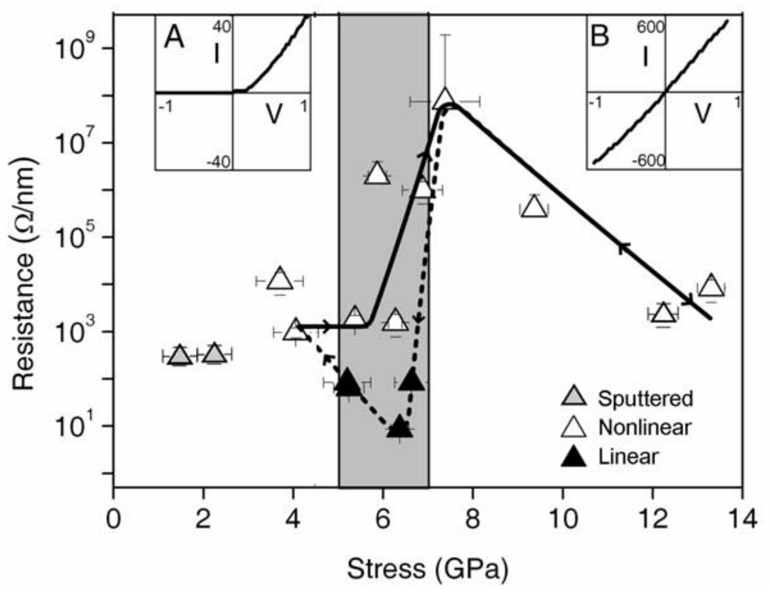
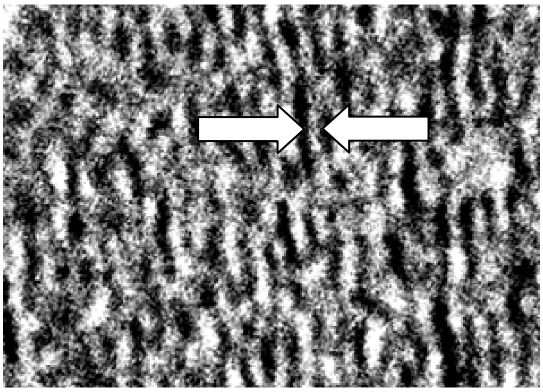
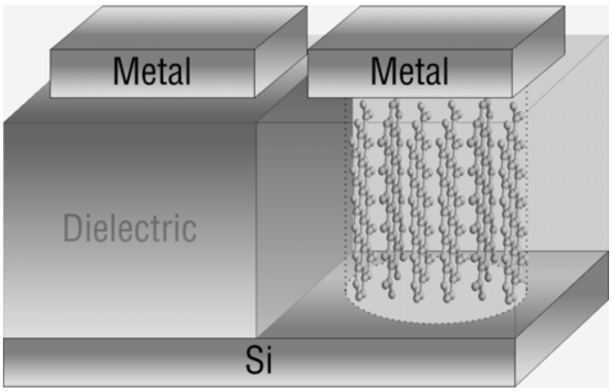


Figure 1. The through-film resistance per nanometre plotted against intrinsic stress for sixteen carbon films. Insets A and B show examples of non-Ohmic and Ohmic current-voltage characteristics obtained from these films. The experimental transition region is shown in grey. The solid and dashed thick lines show the trajectories through the transition region when the ion energy is increased.



(a)



(b)

Figure 2. (a) A high-resolution TEM image of the 0.335nm graphite-like planes (indicated by arrows) aligned perpendicular to the surface of the film and (b) a schematic diagram showing vertically oriented graphite-like sheets as a vertical interconnect material.