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Microstructure and Electrical Properties of In-Situ annealed Carbon Films

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Abstract- The microstructure and electrical properties of in-situ annealed carbon films is studied in this paper. The structure of the films is studied by transmission electron microscopy, electron energy loss spectroscopy and Raman spectroscopy. The microstructure of the films strongly depends on the deposition temperature for the films deposited at high temperatures (higher than 400⁰ C). However, at low temperatures, the substrate bias is the other crucial factor which governs the microstructure of the film. Electrical conductivity of the film strongly depends on the formation of preferred orientation in the microstructure of the films.

I. Introduction

Decrease in the width of traditional copper interconnects in very large scale integration (VLSI) industry leads to a significant increase in resistivity due to the grain boundary scattering and surface roughening. It is believed that the performance and reliability of copper interconnects is going to be the bottleneck for VLSI industries as the interconnect size decreases to less than 45 nm since the electronic mean free path of copper interconnects will be on the same order of the dimensions. Hence, huge efforts have been focused to fabricate and design new materials and structures as alternatives for interconnect industries.

Despite interesting properties of CNTs which introduces this class of material as a potential candidate for interconnect applications, there are still severe practical problems which limit the application of CNTs as interconnect. CNTs can be both metallic and semiconductor according to chirality of the tubes [16]; however, there is not a practical method to specifically grow metallic tubes while semiconducting tubes cannot be used for interconnect applications. Moreover, CNT growth is achieved at relatively high temperatures which is due to high bulk diffusion activation energy of carbon atoms in the catalyst (1.2-1.5 eV) that limits the growth to temperatures higher than 500⁰ C. Here, textured carbon films is introduced and studied as another potential

carbon based candidate for interconnect applications. The anisotropic nature of graphite leads to formation of preferred orientation in the microstructure of the film which in turn results in interesting electrical properties.

II. Current Results

Figure 1 shows the microstructure of the film deposited by “filtered cathodic vacuum arc” (FCVA) at room temperature and 300 V substrate bias. As it's shown from the image and the inset which shows the relative diffraction pattern, the film is purely amorphous in structure.

Figure 1 HRTEM image of the carbon film deposited at room temperature and 300 V substrate bias

Figure 2 shows the corresponding Low-Loss EEL spectra of the film shown in figure 1. As it is shown, a bulk Plasmon peak located at 28.1 eV can be observed which corresponds to a density of 2.49 gr/cm³ and no π Plasmon peak can be detected. Figure 3 on the other hand shows the HRTEM image of the carbon film deposited at 400⁰ C and 300 V substrate bias. As it is observed from both the HRTEM image and the diffraction pattern, a preferred orientation in such a way that (002) basal planes are perpendicular to the substrate can be observed throughout the whole thickness of the film.

Figure 2 Low-Loss EEL spectra of amorphous carbon film deposited at room temperature and 300 V substrate bias

Figure 3 HRTEM image of the carbon film deposited at 400°C and 300 V substrate bias.

The formation and propagation of preferred orientation in the microstructure of the film can be explained using the high internal stress and also the anisotropic nature of graphite crystal structure. High intrinsic stress leads to formation of high strain energy in the system. sp^2 clusters with preferred orientation will form to relieve the strain energy and hence the total energy of the system. Graphite has anisotropic HCP structure. The spacing between carbon atoms in the (002) basal planes is 1.421 Å while the interplanar spacing of (002) planes is 3.354 Å. In the case where any internal or external deviatoric stress field is applied to the structure, the structure tends to reorient

in such a way that the basal planes lie perpendicular to the direction of the highest stress component.

In the case of a-C film, the intrinsic biaxial stress is in the growth plane (perpendicular to the substrate). Therefore, if sufficient energy is transferred to the system, the (002) planes will reorient in the direction perpendicular to the surface.

Figure 4 shows the Low-Loss EEL spectra of the sample shown in figure 3. As it is shown beside a bulk Plasmon peak located at 25.9 eV a bulk Plasmon peak located at 5.6 eV can also be observed which confirms the formation of preferred orientation in the microstructure of the film.

Figure 4 Low-Loss EEL spectra of the carbon film deposited at 400°C and 300 V substrate bias

Figure 5 shows the I-V curve of the amorphous film as well as the film with preferred orientation. As it is shown, the propagation of preferred orientation results a sharp increase in electrical conductivity in a direction perpendicular to the substrate which is mainly due to formation of parallel basal graphitic planes in this orientation.

Figure 5 I-V curve for the (A) amorphous and (B) preferred oriented carbon film