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Highly Conductive Aligned Carbon Film for Interconnect Application

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Abstract- We demonstrate here an amorphous carbon film with a highly conductive transition phase for interconnect application. The uniform orientation of graphite-like sheet provides an effective carriers transport channel, thus significantly improves the conductivity of the amorphous carbon film. The electrical properties of the aligned carbon film are investigated using Kelvin structure. Our results show that the resistivity of aligned carbon film is comparable with that of Cu, and the aligned carbon film holds promise for future interconnect application.

I. INTRODUCTION

Decreasing copper wire dimensions will cause increases in resistivity due to surface roughness and grain boundary scattering [1]. This is further exacerbated by the increase in Cu resistivity, as line dimensions and grain size become comparable to the bulk mean free path (MFP) of electrons (about 40 nm). [2] Innovative material and process solutions are critical to sustain the growth curve according to the *International Technology Roadmap for Semiconductors (ITRS)*. [3] In this regard, the potential of carbon nanotubes (CNTs) as an interconnect material has been recognized. The extraordinary electrical, mechanical, and thermal properties of CNTs may provide near-term solutions for problems in interconnects, chip cooling, etc. in silicon integrated circuit technology. [4-6] However, the disadvantages of CNTs interconnect, such as the relatively high fabrication temperature (chemical vapor deposition, CVD), difficulty of chirality and orientation control may become drawback for the practical application of CNTs in circuit interconnect. Furthermore, the integration of CNTs in CMOS interconnect still need to be improved in order to meet the requirement of mass production. In this work, an amorphous carbon film with a highly conductive transition phase was synthesized and we found that the resistivity of the aligned carbon film was comparable with that of Cu.

II. EXPERIMENT AND RESULTS

The resistance was measured using the four-point crossbridge Kelvin structure, as schematically shown in the Fig.1.[7] A silicon wafer covered with 100 μ m was used as substrate. 200nm metal layer was sputtered as bottom electrode. Thin films of aligned carbon were deposited at 400 $^{\circ}$ C using C ions generated from a dual-bend filtered cathodic arc deposition system operating with a 99.999% pure graphite target at an arc current of 60 A. Another 200nm metal layer was formed on carbon film by sputtering as top electrode.

Figure 1 Schematic diagram of the four-point cross-bridge Kelvin test structure

For the amorphous carbon film deposited at room temperature, the current-voltage measurement showed a nonlinear characteristic with an estimated resistance of 0.5M Ω at a potential of 1V, as shown in Fig 2(b). In case of the aligned carbon film, the high resistance nonlinear current-voltage behavior is replaced by a low resistance linear current-

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voltage characteristic indicative of a good Ohmic contact. The striking different behavior is attributed to the microstructural change of the materials sandwiched between metals. For comparison, a current-voltage curve for a pure copper film is also shown in Fig.2(c), from which one can judge that the resistance of the aligned carbon films is comparable to that of pure copper. The high conductivity underlies the future application of aligned carbon film in integrated circuits interconnect.

Figure 2 (a)Schematic of aligned carbon film and IV characteristics for (b) amorphous carbon film and (c) aligned carbon film

The key to understanding this electrical behavior lies in the microstructure. Transmission electron microscopy (TEM) measurements were carried out to clarify the microstructure of the aligned carbon films. Figure 3(a) shows a cross-sectional bright-field TEM image of a film grown on the surface of Si substrate. The diffraction pattern (inset A) reveals localized graphitic (002) reflections aligned with the plane of the film. Dark-field imaging shows that the microstructure consists entirely of graphitelike sheets aligned normal to the film surface, as seen in the bright field high resolution enlargement in Fig. 3(c) and (d). This orientation is preferred on the basis of energy minimization of turbostratic graphite in a biaxial stress field [8]. It is these films that exhibit low resistance and Ohmic behavior.

Figure 3 (a)TEM images of aligned carbon film on the surface of Si substrate; inset: diffraction pattern of the c-film; (b) dark-field image of the c-film; (c) and (d) are magnified image of the aligned c-film;

In summary, we demonstrate here the synthesis and high conductivity of a carbon film with preferred orientation. The graphitelike sheets aligned normal to the film surface provide an effective electron transport channel, which is the origin of the extremely high conductivity of carbon film. As copper becomes incompetent in the nanoscale on-chip interconnect, the aligned carbon film hold promise for the future application in integrated circuit interconnect.

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