Comparison of Tungsten Contacts formed by FIB and e-beam Depositions


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Carbon nanofiber (CNF) is a promising material for interconnect applications in next-generation integrated circuits. Understanding the temperature dependence of material properties such as conductivity and contact resistance is essential as they critically impact circuit performance. To study the contact resistance between CNF and metal, a test device is prepared by placing a single CNF between a pair of patterned gold (Au) electrodes on a SiO$_2$ substrate. Robust electrical contacts are formed by tungsten (W) deposition using focused ion beam (FIB), with the resulting total resistance smaller than that for the pre-W-deposited device by a factor of 100-1000 [1]. A progressively increasing stressing current is applied to the test device, and the average total resistance during each stress cycle is measured. We have found that the average resistance within each stress cycle decreases with temperature from one cycle to the next [2,3].

As described above, the study of CNF devices with W contacts formed by FIB deposition yielded important new findings. In view of the current continuous downsizing trend of semiconductor devices, metal deposition requires more sophisticated control and finer resolution, as well as better cost-effectiveness than what FIB can offer. In addition, FIB has the potential risk for damages to the devices because of its high energy. To address these issues, we develop an e-beam deposition technique using a gas injection system (GIS) with high precision in controlling gas flow and low beam energy. Deposition by ion beam requires a dual system (FIB and SEM), while e-beam deposition requires only an SEM with a GIS module. The schematic of the GIS is shown in Figure 1, which consists of a narrow nozzle, a pressure gauge, some needle valves, and a source gas bottle. The nozzle is placed at the point where deposition occurs using a manual controller. The tip of the nozzle is moved very close to the surface of the target device by adjusting the height of the SEM stage. In addition, the size of the nozzle is chosen to optimize gas flow. We use WF$_6$ as the source gas for W deposited onto the CNF-Au electrode contacts. Comparison of the results for deposited W by ion and electron beams is important because W is known to form excellent electrical contacts with many materials. At the same time, such a comparison affords us the opportunity to evaluate our e-beam deposition system and the effectiveness of the gas injection process. Parameters such as the working distance from the deposition spot to the nozzle tip, gas flow rate, and gas pressure are examined. Also the electron beam acceleration voltage, emission current, scan mode, and scan time are optimized. Our results indicate that W deposition by e-beam is successful and yield contacts comparable to that obtained using FIB. For example, from energy-dispersive x-ray spectroscopy (EDS) analysis, the W and oxygen contents are about 45 and 40 atomic percent, respectively, for spots deposited with either technique. Figures 2 and 3 show the SEM images of the CNF test devices with deposited W contacts using FIB and e-beam, respectively. In this paper, in additional to EDS results, we present a comparative study of the contact resistance and the temperature dependence of CNF conductivity for test devices with W contacts formed by FIB and e-beam depositions.
References


Figure 1. Schematic diagram of the e-beam deposition system including the GIS.

Figure 2. The SEM images of CNF test device with W deposited by FIB.

Figure 3. The SEM images of CNF test device with W deposited by e-beam.