Observation of mass transport in transfer-free graphene encapsulated copper nanowires by using in-situ transmission electron microscopy

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Cu interconnect distributes the clock and other signals and provides power/ground to the various microelectronic devices. The Cu interconnect requires a diffusion barrier layer to avoid Cu diffusion into the surrounding dielectric and to obtain low electrical resistance. In general, Ta/TaN, Co and Ru deposited by physical vapor deposition (PVD) or chemical vapor deposition (CVD) methods are used as barrier material in Cu interconnects because they have superior gap-filling ability, low resistivity, good adhesion to Cu and no solubility to Cu. However, the size of advanced Cu interconnect has been significantly reduced, reaching the current 10 nm node technology and below, and thus advanced Cu interconnect requires ultrathin and reliable diffusion barrier with the relentless scaling of microelectronic devices. Recently, the graphene, a 2D atomically thin film of carbon atoms arranged in a hexagonal lattice, has been suggested as a new candidate for ultrathin Cu diffusion barrier material owing to its unique characteristics such as excellent electrical and mechanical properties, thermal and chemical stability, and capability to effectively block the diffusion of Cu atoms into dielectric material. With scaling, in addition, the physical properties such as electrical resistivity and electromigration (EM) in Cu interconnect are increasingly influenced by Cu microstructure and adhesion between metallic interconnect and barrier materials. Therefore, it is necessary to investigate the EM mechanism of advanced narrow Cu interconnects wit ultrathin diffusion barrier. Instead of patterned Cu interconnect, in this study, transfer-free graphene encapsulated Cu nanowires were synthesized and a mechanism of EM occurred during the current sweep was investigated by in-situ transmission electron microscopy (TEM). Pristine Cu nanowires with a diameter of about 25 nm were synthesized by a rapid and facile hydrothermal method. Then, Cu nanowires were directly encapsulated with transfer-free graphene by using a thermal CVD process at temperatures ranging from 800 ℃ to 950 ℃. TEM specimens for in-situ experiment were prepared by transferring pristine Cu nanowires and graphene encapsulated Cu nanowires onto the electrical MEMS chips using lift-out system with glass tip. The resistance-time (R-T) characteristics under a current density of 10^6 A/cm^2 were investigated by TEM operated at 200 kV. The relationship between EM phenomena and microstructure of Cu nanowire was observed simultaneously by using in-situ experiment. Direct observation of the microstructural evolution and failure phenomena with electrical measurement allowed us to understand the EM mechanism clearly.