Part III
Interconnect Materials

This part is about interconnect materials. Chapter 7 presents about the materials for diffusion barriers for ULSI copper metallization. The main challenge is to achieve a significant reduction of the barrier thickness while maintaining high conductivity of this ultra-thin layer. In addition, the deposition process must be highly conformal in order to maintain uniform barrier properties throughout the high-aspect trenches and vias of the dual-Damascene process. The leading candidates for achieving this are atomic layer deposition of TaN, Ru, and WNC/Ru bi-layers. Self-assembled molecular layers and self-forming barriers are also possible deposition methodologies for reaching this goal. In addition, electroless deposition, in particular that of CoWP, is the leading candidate for use as a capping layer, although the industry is concerned with electrical shorts, which may be created by this metallic barrier. The motivation for the introduction of copper metallization and difficulties of implementing copper metallization have been discussed in one of the section of this chapter. Types of diffusion barriers and some of the deposition methods for diffusion barriers have also been discussed in detail. Evaluation of diffusion barriers for copper metallization is presented in detail. Chapter 8 gives the introductory idea about silicides used as contact materials; mainly TiS_2, $CoSi_2$, NiSi, SiGe into silicide/Si contacts have been discussed briefly. Some important properties of these materials are summarized. The formation process, advantages, and disadvantages of these silicides are separately mentioned. Additionally, several technologies to control crystalline and electrical properties of silicide contacts are also discussed. Chapter 9 gives the overview of electrical properties of the materials used in ULSI metallization. Large-grained Cu interconnects and ultrathin barrier layers are essential to realize low-resistance nanoscale Cu interconnects in the future ULSI devices. For development of a fabrication technique of large-grained Cu interconnects, grain growth mechanism of Cu thin films was understood. A new grain growth model for Cu thin films was proposed based on the strain energy criterion model at temperatures where dislocation glide was the dominant strain relaxation mechanism. The fabrication technique to self-form the thin barrier layers in Cu(Ti) alloy films by annealing at relatively low temperatures ($\sim$400°C) was demonstrated. The selection rule of the Cu alloy elements required for the barrier self-formation and low film resistivity was proposed based on understanding of the self-formation mechanism of the barrier layer. Chapter 10 reviews low-κ materials and proposes future development. Though low-κ materials have been actively investigated by many researchers, target values of ITRS (International Technology Roadmap for Semiconductor) have not been achieved. To reduce RC delay, both lower resistance wiring material, copper, and low-κ material are necessary. Especially for recent IC chips, ratio of BEP (back-end process) has rapidly increased with increasing wiring layers. Chapter 11 discussed about the electrical and mechanical characteristics of air-bridge copper interconnects. Multilevel air-bridge Cu interconnects with air gaps in the M1 and M2 metal line level were analyzed to evaluate their electrical and stress characteristics. As variations of the low-k dielectrics, three materials porous MSQ, SiCOH, and TEOS were considered. The combination of fully dense SiCOH dielectric in the M2 level and air-bridging down to the via 1 level was found to provide an effective dielectric constant of 2.27. This meets the Technology Roadmap requirement for the 45 nm technology node and is extendable to the 32 nm node. Simulation showed that the stress levels induced during processing in the air-bridge Cu lines and vias using SiCOH as a dielectric were intermediate between those with TEOS and p-MSQ. The effective modulus B was calculated to evaluate the effect of air-bridge structure on mechanical integrity. The result showed that SiCOH and p-MSQ provide a similar degree of confinement to Cu lines, compared with TEOS which provides more confinement due to its mechanical rigidity. Chapter 12 discussed about theatomic layer deposition (ALD) seed layers for plating and electroless plating. Metal ALD is very challenging due to limited precursor selection and the necessity of an organic reducing agent. Pd ALD is a significant improvement over the acid-bath solution route to Pd activation. Ultra-thin films 12–50 Å that are highly conformal can be deposited via $Pd^{II}(hfac)_2$ and hydrogen via a remote hydrogen plasma or glyoxylic acid. Improvement is certainly possible with these ultra-thin metallic layers deposited via ALD. Electroless copper was deposited with ease on these Pd PA-ALD layers. Electroless copper can either be deposited in “conformal” mode or “trench fill” mode depending on the experimental process parameters employed.