

Chapter 7

Conclusions and Suggestions for Future Work

7.1 Conclusions

In this dissertation, some integrated issues of promising low-k materials were investigated. Firstly, the study on the impact of O₂ plasma ashing on low-k materials has been demonstrated. The study on the effect of H₂, NH₃ plasma, and TMCS/HMDS treatments on low-k materials for photoresist stripping was also presented. The study on the impact of CMP process on low-k MSZ and PPSZ films for interconnect applications was investigated. In addition, a new method of improving the polishing rate of MSZ and PPSZ films is also demonstrated.

As for the electron beam (e-beam) direct patterning technology, the effect of e-beam exposure on inorganic low-k HSQ was studied. Additionally, the effect of electron curing on organic low-k MSZ material was explored. Also, the feasibility of e-beam direct patterning on organic ultra low-k POSG for ULSI interconnect applications was evaluated. Finally, the leakage behavior of the e-beam exposed porous POSG film was studied in this dissertation.

7.1.1 Study on the impact of plasma treatment on low-k Methylsilsequiazane (MSZ) for interconnection applications

In this study, we investigated the intrinsic properties of low-k MSZ films and the

effect of various plasma treatments on MSZ film in detail. The MSZ film has a high thermal stability up to 550 °C. Its dielectric properties will be degraded by O₂ plasma ashing during photoresist stripping process. The H₂ and NH₃ plasma pre-treatments can effectively avoid the dielectric degradation during O₂ plasma ashing process. Also, the TMCS/HMDS chemical post-treatments can recover the dielectric properties of O₂ plasma treated MSZ film by replacing the Si-OH bonds with Si-O-Si(CH₃)₃ hydrophobic bonds.

7.1.2 Study on the CMP of Low-k Methylsilsesquiazane for multilevel interconnection application

In this work, characteristics of low-k methyl-silsesquiazane (MSZ) for the chemical- mechanical-planarization (CMP) process using various slurries were investigated in detail. Also, oxygen plasma pretreatment was used to improve the polishing rate of MSZ. The low-dielectric-constant (low-k) MSZ were prepared by a spin-on deposition (SOD) process. The resultant wafers were followed by CMP process. In addition, oxygen plasma treatment was implemented on MSZ before CMP process. Electrical and material analyses were utilized to explore the characteristics of post-CMP MSZ. Experimental results showed that the polish rate of MSZ film with O₂ plasma pre-treatment was increased as much as twice in magnitude, as compared to that of the MSZ without O₂ plasma pre-treatment. In addition, the post-CMP MSZ with TaN and Cu slurries exhibited superior electrical properties. These results indicate that the MSZ film is compatible with CMP process during Cu damascene manufacture.

7.1.3 Study on the CMP of Ultra Low-k Material Porous-Polysilazane for interconnection applications

In this study, we investigated the impact of chemical mechanical polishing (CMP) on an ultra low dielectric constant (ultra low-k) material Porous-Polysilazane (PPSZ) with various slurries during interconnect manufacture process. Since the CMP processing of metals such as TaN and Cu are inevitable steps for interconnect fabrication, we have utilized two types of slurries (marked as TaN and Cu slurries) to evaluate their effects on the dielectric properties of PPSZ films. In addition, the effect of oxygen plasma for CMP of PPSZ was also studied. Electrical and material analyses have shown surface planarity and dielectric properties of PPSZ films will not be degraded during these metal CMP processes. Moreover, the polishing rate of PPSZ film with O₂ plasma pre-treatment is increased as much as twice of magnitude than that of PPSZ only with SS-25 slurry. This indicates the ultra low-k PPSZ film is promising for inter-level dielectric (ILD) applications in ultra large scale integrated circuits (ULSI) technology.

7.1.4 Direct Patterning of Low-k Hydrogen Silsesquioxane (HSQ) using E-Beam Lithography Technology

The dielectric properties of low dielectric constant hydrogen silsesquioxane (HSQ) are investigated with electron-beam (e-beam) direct patterning for intermetal dielectric applications. The optimum doses of e-beam exposure are identified by Fourier transform infrared spectroscopy and electrical analysis. The electrical properties of e-beam exposed HSQ with various post-treatments, such as immersing in tetramethylammonium hydroxide (TMAH) development solution and thermal

annealing, are evaluated. In the aspect of direct patterning, the portion of HSQ films exposed by e-beam will be cross-link and form desirable pattern. Then, the residue is dissolved in an aqueous solution comprising 2.38 % TMAH. A minimized linewidth of 60 nm is also demonstrated with e-beam direct patterning technology. These results indicate the e-beam direct patterning process is a promising technique for next IC fabrication generation.

7.1.5 Study on the Feasibility of Electro-Beam Direct Patterning on Low-k MSZ for Interconnection Application

In this work, e-beam lithography for low-k MSZ as inter-metal dielectric (IMD) has been investigated in this chapter. Materials analysis and electrical properties show e-beam exposure tends to give the as-hydrated MSZ energy to partial cross-linking the matrix material into three-dimensional structure. However, the energy of e-beam is not enough to form the perfect three-dimensional structure of MSZ and remain many defect and leakage paths in bulk MSZ. This makes both leakage current and dielectric constant of MSZ film breakdown. Therefore, an additional post-exposure furnace annealing can make the electrical properties of e-beam exposed MSZ recover to be similar to that of traditional furnace cured one. The sensitivity of e-beam exposure on MSZ film was about 500 uC /cm^2 . Although the pattern of e-beam exposed MSZ film can be obtained in this study, an additional study is required to perfect the patterning resolution. It is believe that the method can be incorporated into next generation of multilevel interconnect systems as the devices shrink into nano-scale regimes.

7.1.6 Exploration of the Effect of Electron Beam Curing on Organic Ultra Low-k Porous Organosilicate Glass (POSG) Material

The effect of electron beam (e-beam) curing on an ultra low dielectric constant material, porous organosilicate glass (POSG) is investigated. In this technology, the dielectric regions irradiated by e-beam will be cross-linked, forming the desired patterns. Meanwhile, the regions without e-beam illumination are dissolvable in a mingled solvent of 2.38 wt% tetra-methyl ammonium hydroxide (TMAH) and methanol with the ratio of 1:8. In this work, the possible doses of e-beam exposed POSG are decided by Fourier transform infrared spectroscopy, n&k 1200 analyzer and electrical analyses. The experimental results expressed that the minimum dosage to cure POSG film is 6 uC/cm^2 , which is similar to commercial e-beam resist. Additionally, a scanning electron microscope (SEM) image of homemade pattern was made to evaluate the process practicability. In addition, the experimental results reveal that the porosity of e-beam exposed POSG will be reduced after development and thermal annealing process. This will result in the lower dielectric constant of POSG film to about 1.89. In addition, the leakage current behaviors of POSG films will be transformed from schottky emission into space-charge-limited current conduction mechanism after e-beam exposure process.

7.2 Suggestions for Future Work

There are a number of topics relevant to this dissertation which deserves further studies. The following topics are suggested for future work.

- (1) Further study on the porous material ($k < 2.0$) organic and inorganic silica-based materials for future application.
- (2) Study on the effect of e-beam direct patterning technology for underlain MOSFET devices.
- (3) Evaluation of the electrical reliability of Cu and e-beam exposed materials for interconnect applications.
- (4) Investigation of the characteristics of low-k material in high frequency environment.
- (5) Investigation of the dielectric characteristics of low-k materials under low-temperature environment (temperature < 30 K).
- (6) Evaluation of photo-electrical characteristics of low-k materials for TFTLCD applications.
- (7) Integration the low-k materials with poly-Si TFT devices for TFTLCD applications.
- (8) Investigation of the reliability issues of low-k materials with poly-Si devices for TFTLCD applications.