Photosensitive low-dielectric-constant films for ULSI interconnects

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1. Introduction

The miniaturization of ultra-large-scale-integrated (ULSI) circuit is ruled by the scaling rule [1]. According to the scaling rule with miniaturization, the current interconnect technologies are faced with the increasing of the number of the interconnect layer. This is because the ULSI interconnect delay increases. Then the interconnect technologies with copper (Cu) wire and low dielectric interlayer film (low-k film) are needed for future ULSI. Methylsilsesquioxane (MSQ) has the low dielectric constant k=2.7 and is a candidate for the dielectric interlayer film. For future use, some aspects of methylsilsesquioxane are investigated [2].

Polymethylsilazane is the precursor component of MSQ. When the photo-acid generator (PAG) molecule is added to polymethylsilazane, and which acquires the photosensitivity. Photosensitive polymethylsilazane has sensitivity to ultra-violet light and electron-beam, and so on. Then the lithographies of photosensitive MSQ were examined by using ultra-violet light, KrF lazar, electron beam, and SOR X-ray [3-6]. In these lithographies the via and trench patterns were formed directly without using dryetching. The dryechless processes using photosensitive MSQ reduces the number of integration step, and enables the damascene interconnect process easily.

In this paper the pre-humidification process of MSQ is discussed for a solution to high aspect ratio.

2. Experiments

Electron-beam lithography was performed by use of HL-700 electron-beam stepper. The electron-beam energy was 50 keV. Photosensitive polymethylsilazane were spin-coated to the thickness of 350 nm on 2inch Si(100) wafers at 2000 rpm for 20 sec. It was prebaked at 90 ℃ for 1minute. Moisture absorption treatment was performed in the humid environment (25 ℃, 80 % relative humidity) for 10 minutes. After moisture absorption treatment, electron-beam lithography was carried out. The wafer was developed in 2.38 % tetrakis-methyl-ammonium-hydride (TMAH) aqueous solution for 90 seconds. Then the wafer was rinsed in deionised water for 2 minute, and was spin-dried.

The lithographic characters were measured by use of scanning electron microscopy (SEM).

3. Results and Discussion

The Fourier transform infrared (FTIR) spectroscopy spectra of photosensitive MSQ are shown in Fig.1. After curing Si-NH peaks (3413, 1172, 943 cm^{-1}) disappeared, and Si-O peaks (1021, 780 cm^{-1}) appeared. Then Si-O bonds replaced the Si-NH bonds. The refractive index, measured by spectroscopic ellipsometry, was 1.36.

The electron-beam exposure characteristic curves of photosensitive MSQ are shown in Fig.2. The critical electron-beam dose of 100 nm design size was 66 μC/cm^2. The feature sizes of developed patterns versus exposure dose of photosensitive MSQ are shown in Fig.3. The minimal feature size was 126 nm at 93 μC/cm^2. This feature size gives the aspect ratio 2.7 (see Fig.4). The SEM micrographs of photosensitive MSQ are shown in Fig.5 and Fig.6.

4. Conclusion

Characteristics of photosensitive MSQ low-k film were investigated in terms of electron-beam lithography. Patterning of photosensitive MSQ in pre-humidification process showed high aspect ratio. The minimal feature size was 126 nm, and the aspect ratio was 2.7.

Acknowledgment

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References

[1] R.H. Dennard, F.H. Gaensslen, H-N. Yu, V.L. Rideout, E. Bassous, and A.R. LeBlanc, IEEE J. Solid-State Circuits, **9**, 6 (1974).

[2] S. Mukaigawa, T. Aoki, Y. Shimizu, and T. Kikkawa, Jpn.J.Appl.Phys., **39**, 2189 (2000).

[3] T. Kikkawa, T. Nagahara, and H. Matsuo, Appl. Phys. Lett. **78**, 2557 (2001).

[4] M. Tada, T. Ogura, and Y. Hayashi, The 2002 Int. Conf. SOLID STATE DEVICES AND MATERIALS, p44 (2002).

[5] S. Kuroki, T. Kikkawa, H. Kochiya, and S. Shishiguchi, The 2002 Int. Conf. SOLID STATE DEVICES AND MATERIALS, p464 (2002).

[6] S. Kuroki, T. Kikkawa, H. Kochiya, and S. Shishiguchi, to be published, Jpn. J. Appl. Phys. **42**, 4B (2003).

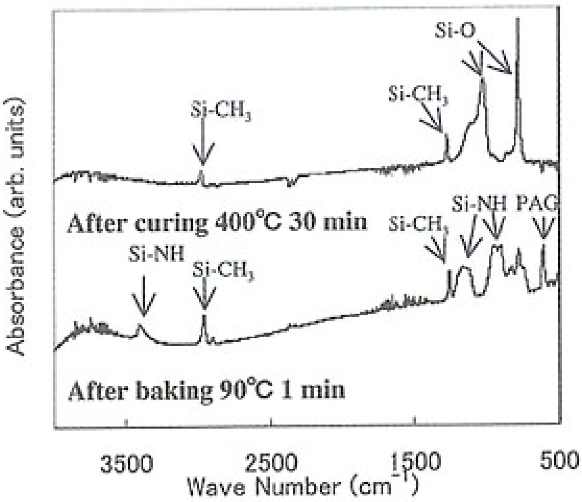


Fig. 1. FTIR spectra of the photosensitive MSQ Film before and after curing.

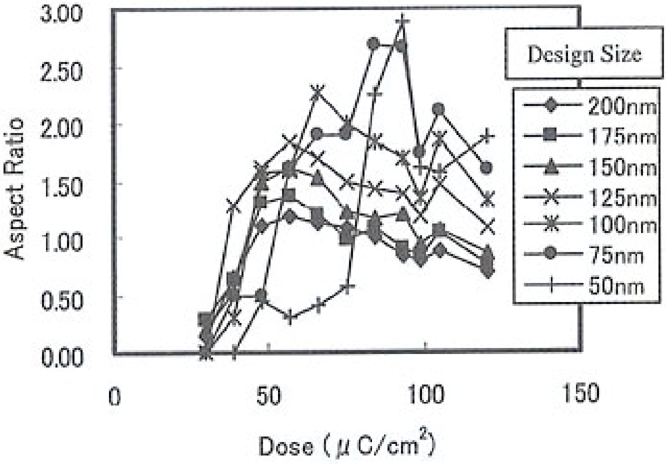


Fig. 4. The aspect ratio versus electron-beam exposure dose: measurements were performed at the line and space patterns (L&S=1:5).

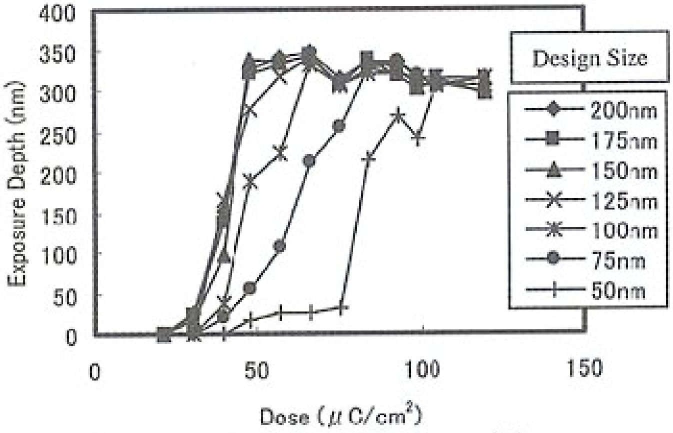
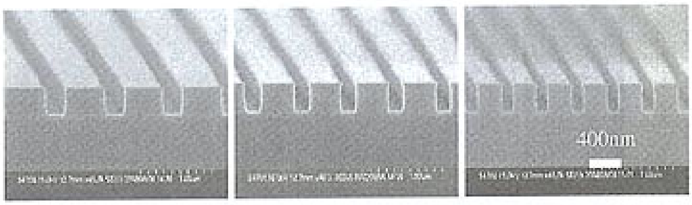


Fig. 2. Electron-beam exposure characteristic curves for photosensitive MSQ: measurements were performed at the line and space patterns (L&S=1:5).



(a) 125 nm (b) 100 nm (c) 75 nm

Fig.5. SEM micrographs of line patterns (exposure dose: 93 μC/cm^2, L&S=1:5). Arabic numbers under the micrographs are design size.

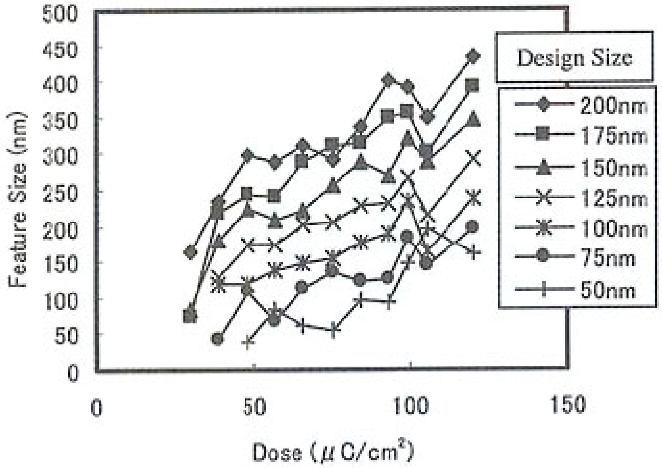
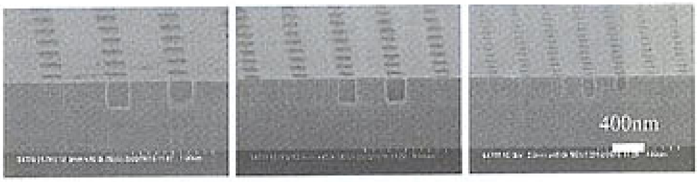


Fig. 3.Measured feature size versus electron-beam exposure dose: measurements were performed at the line and space patterns (L&S=1:5).



(a) 200 nm (b) 150 nm (c) 100 nm

Fig.6. SEM micrographs of hole patterns (exposure dose: 93 μC/cm^2). Arabic numbers under the micrographs are design size.

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OUTLINE

1. Introduction
2. Photo-acid Amplified Mechanism
3. SEM micrographs
4. Lithographic Characteristics
6. Summary

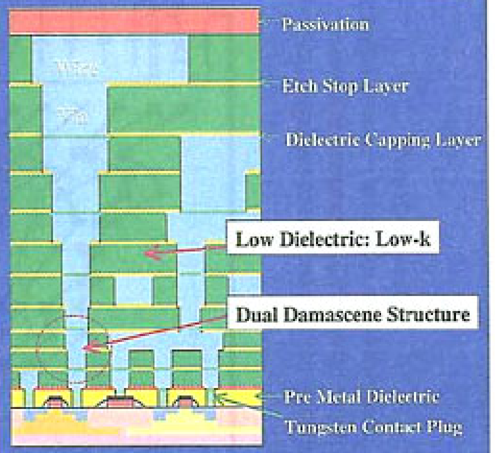
Introduction

Requirements of Low-k

Avoidance of RC delay in LSI
→ Technical advantage

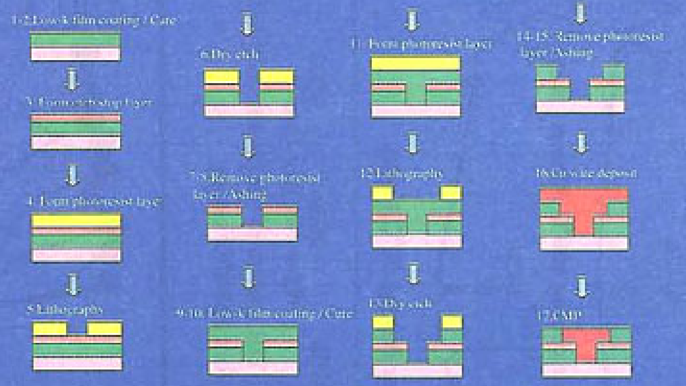
Lower power consumption in LSI
→ Reduction of environmental load

Reduction of number of interconnect layers
→ Reduction of production cost

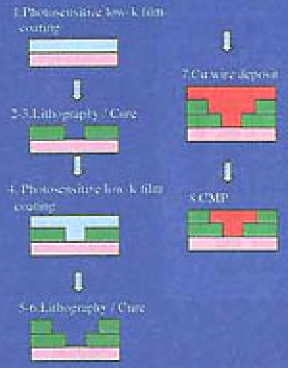


CANDIDATE:
Photosensitive Methylsilsesquioxane (MSQ) (k=2.7)

Standard Dual Damascene Process



Dual Damascene Process with Photosensitive MSQ

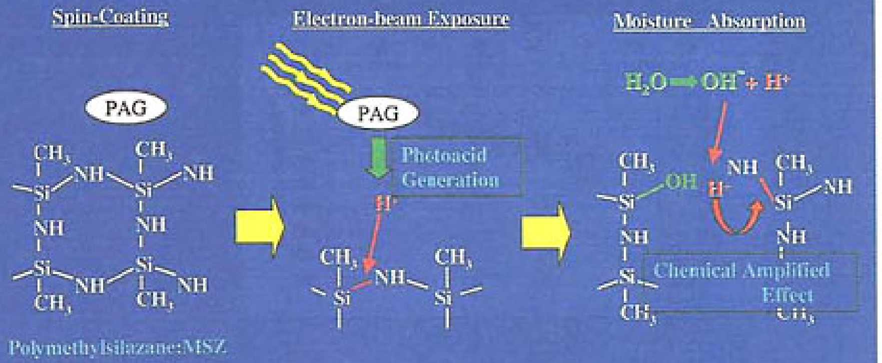


Reduction of process step
→ Reduction of production cost

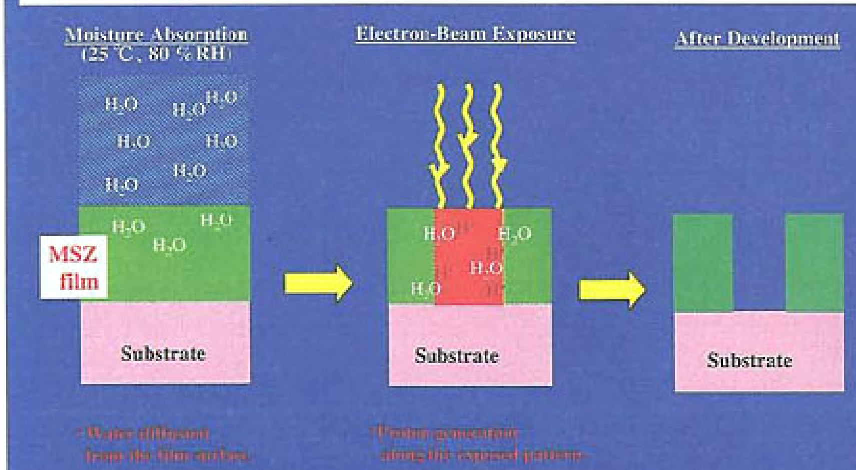
Disuse of etch stop layer
→ Reduction of effective dielectric constant

c.f., dielectric constant
of etch stop layer (SiN) k=7

Photo-acid Amplified Mechanism of Photosensitive MSQ



Macroscopic Picture



Process Flow: Pre-Humidification Process

Wafer: 2 inch

Coating:
Photosensitive MSQ

- Spin-Coating : 2000 rpm, 20 sec
- Pre-Baking : 90 ℃, 60 sec
- Moisture Absorption : 25 ℃, 80 %RH, 10 min
- Electron-Beam Exposure
- Development : TMAH aq. (2.38 %), 90 sec
- Rinse : Deionised Water, 60 sec
- Spin-Dry

SEM micrographs: Line pattern

L/S=1:5
Electron-Beam Dose: 93 μ C/cm²

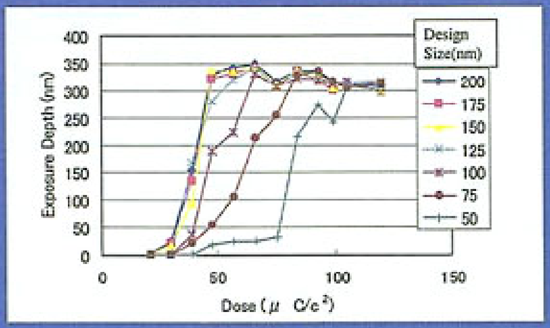
125 nm 100 nm 75 nm

SEM micrographs: Hole pattern

Electron-Beam Dose: 93 μ C/cm²

200 nm 150 nm 100 nm

Exposure Depth versus Electron-beam Dose

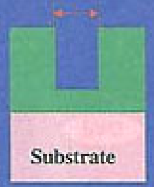


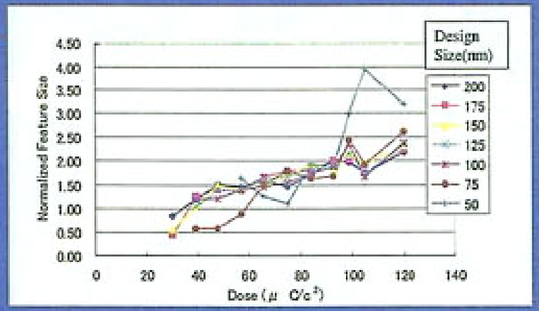
Exposure depth was dependent on electron-beam exposure dose. Threshold electron-beam dose was dependent on design size. Threshold electron-beam dose for 100 nm design size line pattern was [illegible] μ C/cm²

Measured Feature Size versus Electron-Beam Dose

Normalized Feature Size

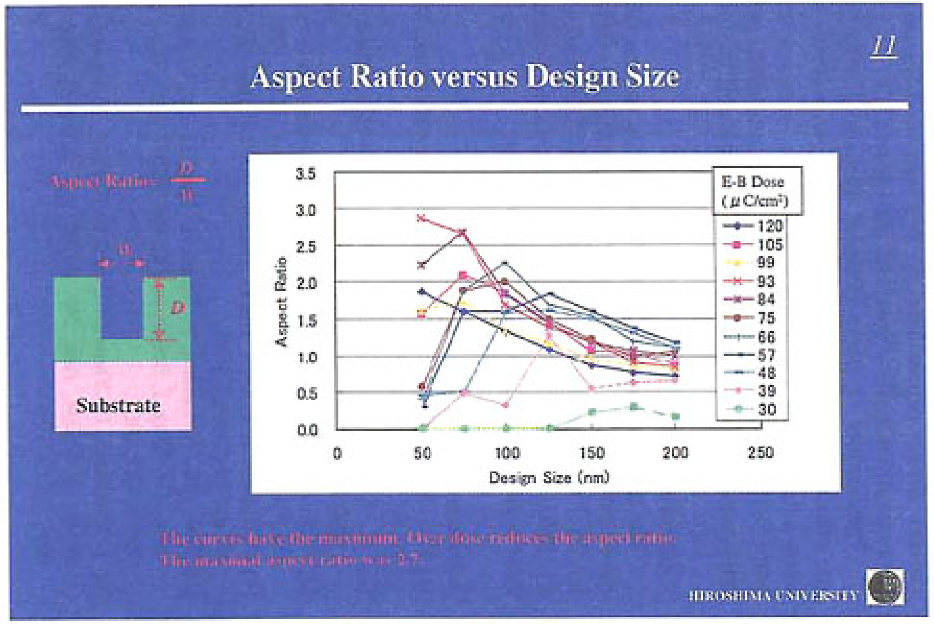
$$= \frac{\text{Measured Feature Size}}{\text{Design Size}}$$





Feature size was dependent on electron-beam exposure dose. The curves of this graph have same slope. The minimal feature size was 126 nm.

Aspect Ratio versus Design Size



The curves have the maximum. Over dose reduces the aspect ratio.
The maximal aspect ratio was 2.7.

SUMMARY

Characteristics of photosensitive MSQ low-*k* dielectric film were investigated by electron-beam lithography.

Patterning of photosensitive MSQ in pre-humidification process showed high aspect ratio. The minimal feature size was 126 nm, and the aspect ratio was 2.7.

Acknowledgment

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