Extended Abstracts of the 2002 International Conference on Solid State Devices and Materials, Nagoya, 2002, pp. 464-465

P3-23

Direct Patterning of Low-*k* Dielectric Films using X-Ray Lithography

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1. Introduction

Photosensitive methylpolysilazane for electron-beam lithography and ultraviolet lithography has been developed as a low-k interlayer dielectric (ILD) film [1]. The photosensitivity enables us to form via and trench patterns directly in the ILD films without using dry etching. When X-ray lithography will be introduced as a future lithography technology, synchrotron orbital radiation (SOR) is an excellent X-ray source with high intensity and high directivity.

In this paper, characteristics of a photosensitive low-k ILD film for SOR X-ray lithography is investigated.

2. Experiments

A photosensitive methylpolysilazane, which consists of a phtoacid generator (PAG) as a chemical amplifier and methylpolysilazane as a base material, was investigated.

After HMDS treatment, 500 nm thick photosensitive methylpolysilazane was spin-coated on 8 -inch Si (100) wafers at 1500 rpm for 20 sec. It was pre-baked at 90°C for 1 minute. The wafer was exposed to SOR X-ray with Ta mask. Minimum feature size of lines and spaces was 100 nm and the ratio of line and spaces was 1:3. After X-ray exposure the wafer was placed in humid environment (23°C, 50% relative humidity) for 20 minutes and 40 minutes, respectively. It was developed in 2.38% tetrakis-methyl-ammonium-hydride (TMAH) aqueous solution for 1 minute. Then the wafer was rinsed in deionised water for 1 minute, and was spin-dried.

Lithographic characteristics were analysed by scanning electron beam microscopy (SEM).

3. Results and Discussion

The X-ray exposure characteristic curves of photosensitive methylpolysilazane low-k films are shown in Fig.1. Threshold X-ray doses (20% thickness) for the films with 20 and 40 minutes moisture treatments were 7000 and 5200 mA·s, respectively. Gamma values (Δthichness/Δdose) for 20-min and 40-min samples are 2.0 and 1.4, respectively. It is found that longer moisture absorption time was necessary for shorter exposure time. This is because H_2O is necessary for the hydrolysis chemical reaction of the photosensitive low-k film for changing Si-N-H bonds in the methylpolysilazane to Si-O-H bonds, which makes the low-k film to be soluble in PEGMEA solution. It is also important that the X-ray exposure generates protons (H^+) due to chemical amplification reaction by the PAG, resulting in breaking Si-N-H bonds.

Feature sizes versus X-ray exposure doses of developed patterns with 20- and 40-min moisture absorptions are shown in Figs.2.(a) and 2.(b), respectively. It is found that the measured feature sizes were influenced by X-ray exposed doses. This is because higher X-ray exposure dose produces larger number of protons due to the PAG, resulting in the larger area of chemical reaction. The critical X-ray doses for the designed pattern sizes with 20 and 40 min. moisture absorption were approximately 8000 and 5500 mA·s , respectively.

The SEM images are shown in Fig.3. The minimum feature size of 80 nm was formed, which was limited by the photo-mask fabrication technology.

Exposure depth versus exposure dose was shown in Fig.4. SOR X-ray can penetrate the film deeply, however, the depth of the developed pattern was limited. Measured aspect ratios of the patterns were ranging from 0.5 to 2.0, depending on the design feature size. It suggests that there should be two diffusion limited processes; one is H_2O diffusion, and the other is H^+ diffusion. For narrower line widths a total number of generated protons may limit the feature size, while for wider line widths H_2O diffusion from the surface of the film may limit the depth.

4. Conclusion

Characteristics of photosensitive methylpolysilazane low-k film were investigated in terms of SOR X-ray lithography. It is found that the methylpolysilazane with a photoacid generator could be patterned by the X-ray lithography, and the minimum feature size of line and space was 0.08μm. The photosensitive low-k film could be one of possible candidates for future low-k interlayer dielectric films.

Acknowledgment

Part of this work was supported by NEDO under the management of ASET in METI's R&D.

References

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

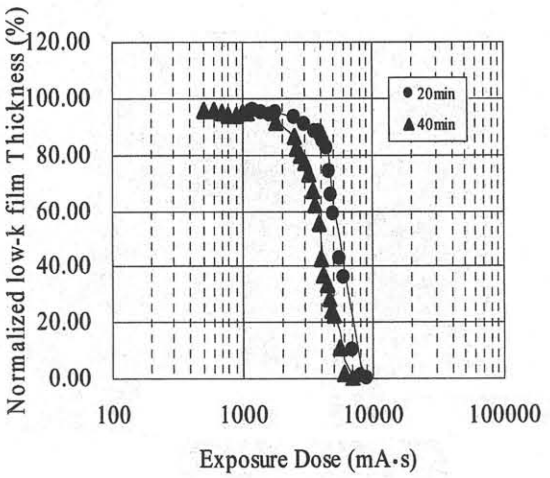


Fig.1. SOR exposure characteristic curves for photosensitive methylpolysilazane.

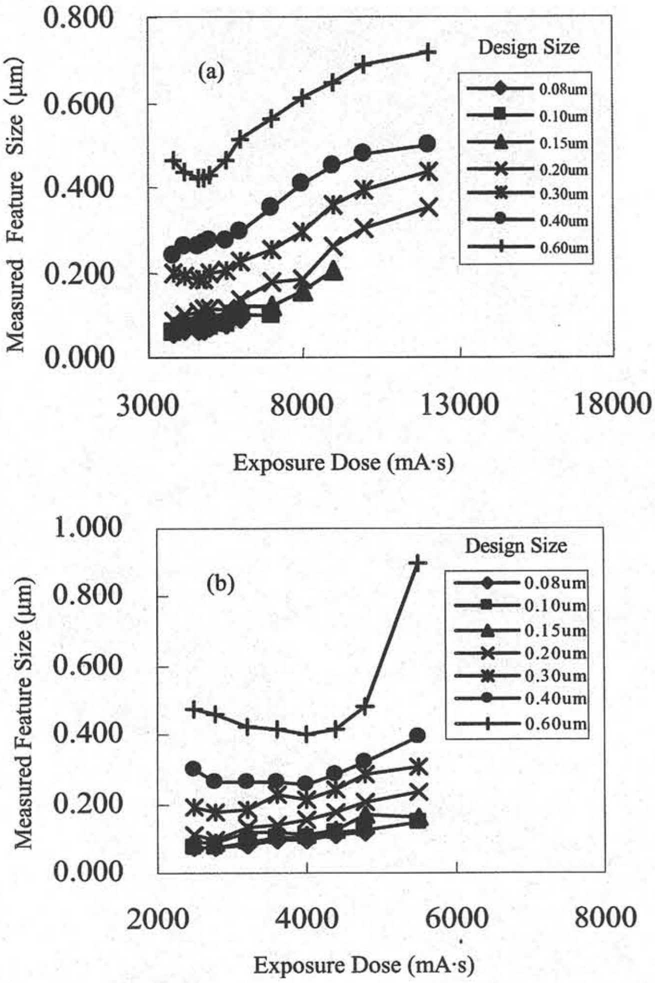
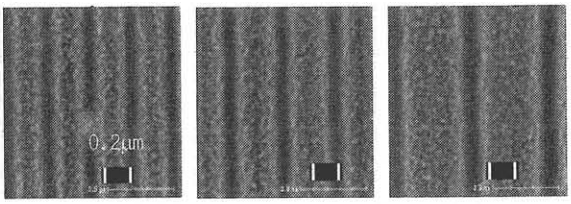


Fig.2. Measured feature size versus SOR X-ray dose : (a) 20min. moisture absorption, (b) 40 min. moisture absorption.



(a) 0.08 μ m (b) 0.10 μ m (c) 0.15 μ m

Fig.3. SEM micrographs of line patterns (40 min. 4000mA·s).

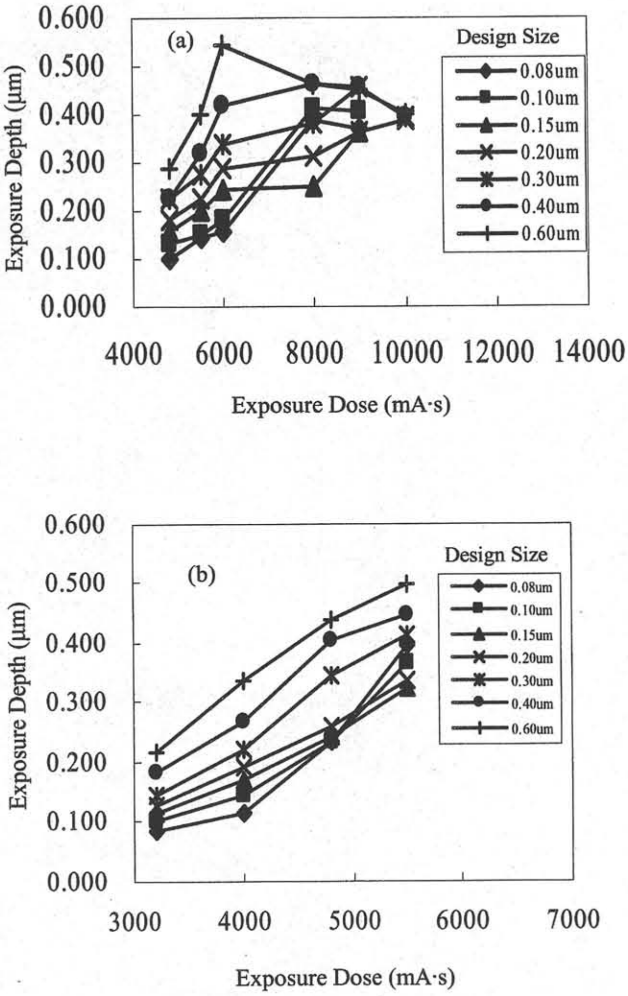


Fig.4. Exposure depth as a function of SOR X-ray dose : (a) 20 min. moisture absorption, (b) 40 min. moisture absorption.