BILAYER E-BEAM/DUV RESIST SYSTEMS

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ABSTRACT

Two bilayer E-beam/DUV resist schemes were developed using a DUV sensitive PMGI planarization layer and two E-beam sensitive imaging layers. PMMA and Olin-Hunt Waycoat HEBR-214 were used as imaging layers. The HEBR-214/ PMGI system is totally aqueous developable. Both systems offer several advantages over other bilayer systems including thermal stability, low interfacial layer formation, and low toxicity.

INTRODUCTION

As semiconductor technologies continue to push into submicron regimes, more exotic exposure systems and photoresist schemes will be needed to meet demanding lithography tolerances. Direct write Electron beam (E-beam) exposure systems offer enhanced resolution and level to level registration. For these reasons, E-beam systems are frequently used for imaging critical dimensions. The resolution capabilities of E-beam exposure techniques, however, can be limited by electron backscattering phenomena and substrate topography. Multilayer resist schemes (MLR) can be successfully used to minimize these problems and further improve the resolution attained with the E-beam process.

Bilayer resist schemes are the most practical MLR processes that can be implemented in a manufacturing environment. The Portable Conformable Mask process can be used for E-beam lithography by coating a deep ultraviolet (DUV) sensistive resist on the substrate which acts as a planarizarion layer over surface topography. An E-beam sensitive resist is then spun directly onto the planarization layer, and is referred to as the imaging layer. It is possible to attain very uniform imaging layer thicknesses to ensure high resolution and good linewidth control. Exposure, in this case with an E-beam source, and development of the imaging layer creates a contact mask for the bottom layer. A DUV flood exposure followed by development of the bottom layer completes the image transfer to the substrate.

Precise material characteristics are required for MLR processes. Polydimethylglutarimide (PMGI) offers several advantages over other underlayer candidates. Besides DUV sensitivity, PMGI exhibits aqueous base solubility, low toxicity,

and a high glass transition temperature (Tg approximately 185C) allowing for increased temperature processing [1]. Its solubility in aqueous base developers eliminates safety hazards and disposal requirements associated with organic solvents [2]. Furthermore, PMGI is insoluble in most casting solvents, thus minimizing the formation of interfacial layers and subsequent scumming problems, caused by intermixing with the imaging layer [3].

The imaging layer must meet two requirements. First, the resist must be an E-beam sensitive material. Second, the resist must provide an effective DUV mask for exposure of the planarization layer. One candidate is the novolak based resin Waycoat HEBR-214 manufactured by Olin-Hunt. HEBR-214 is a high contrast, aqueous base developable resist. It has good sensitivity, approximately 20 uC/cm2 for a 4 minute develop in Waycoat PLSI (5:4). Since the HEBR-214 is a novolak based resist, it should perform well as a DUV mask. Another advantage of the HEBR-214 is that it is near UV sensitive, making it compatible for exposure on G-line steppers [4]. Another candidate for imaging layer is PMMA. PMMA is a DUV sensitive as well as an E-beam sensitive resist. It typically requires approximately 100 uC/cm2, making it less sensitive than the HEBR-214. Although it is DUV sensitive, it can still be used as a mask for the flood exposure of the bottom layer. PMMA requires an organic solvent for development, so significant thickness loss in the PMGI aqueous base developer is not expected [5]. This project will investigate the use of both materials as possible imaging layers in a bilayer resist scheme using PMGI as a planarization material.

EXPERIMENT

The first part of the project entailed the preparation of 20 three inch wafers. All of the wafers were RCA cleaned. HMDS was spun at 5000 RPM for 30 seconds. Seventeen of these wafers were then coated with approximately one micron of PMGI using a 5 second spread cycle at 500 RPM followed by a 3200 RPM spin for 30 seconds. They were then be cured at 260 C for one hour in a convection oven. The remaining 3 wafers were coated with 1 micron of PMMA (spun at 4000 RPM for 30 seconds) and baked at 140 C for 30 minutes in a convection oven. Ten of the PMGI coated wafers were spun with approximately .5 microns of HEBR-214 resist (5000 RPM for 30 sec), and then softbaked at 100 C for 30 minutes. Four of the remaining PMGI coated wafers were then coated with a one micron thick imaging layer of PMMA, and baked at 140 C for 30 minutes.

To verfify the thermal stability of the PMGI, five PMGI/HEBR-214 wafers were exposed on a Kasper Aligner contact printer using a dose of 35 mJ/cm2 and a test mask which had several line/space features. They were developed in Waycoat PLSI developer (5:4) for 1 minute. Since HEBR-214 caps were not

desired in this portion of the experiment, no post bake was performed. This ensured the removal of the HEBR-214 in the underlayer develop step. The wafers were cleaved and DUV flood exposed using a mercury arc source from a Kasper Aligner. The source was placed in a box to eliminate any optics. An exposure time of 75 minutes was required for a 1 minute develop in KTI ZX-934 developer (1:1). The optimum dose was determined by exposing several PMGI coated samples at different exposure times ranging from 30 to 75 minutes. The time to clear was determined by developing the samples in KTI ZX-934 developer (1:1).

The PMGI patterned wafers were then baked at temperatures ranging from 120C to 200C in a convection oven for 30 minutes to represent worst case thermal conditions. SEM photographs were taken of each sample to determine the thermal flow point of the PMGI resist.

The solubility of PMGI in the HEBR-214 casting solvent was examined by monitoring the thickness loss of PMGI in Waycoat PLSI thinner as a function of time. The thickness loss of PMMA, a commonly used planarization layer, in the PLSI thinner was also monitored for comparison. PMGI and PMMA coated wafers were sectioned into half inch squares and immersed in the casting solvent. Immersion times of 0 to 60 minutes were explored. Thickness of the remaining PMGI or PMMA was measured with the Nanospec. The amount of thickness loss provided an estimate of the degree of intermixing between the planarizing and imaging layers.

The second part of the project involved performing the bilayer process and analysis of the resulting images. The remaining HEBR-214/PMGI wafers and the PMMA/PMGI wafers were sectioned into half inch squares and mounted onto Cambridge SEM studs. The doses used for the HEBR-214 samples were 20, 30, and 40 uC/cm2. The scan time, t, required for each exposure was determined using the following relationship:

$$t = (DOSE \times AREA) / I \qquad (1)$$

where I is the current in the SEM as measured by a Faraday Cup. Three exposures for each dose were done. Optical exposure of the HEBR-214/PMGI on the Kasper Aligner contact printer was also done for comparison. Similarly, the PMMA was exposed at doses of 100, 150, and 200 uC/cm2 on the SEM. All of the wafers were then post baked at 140 C for 30 minutes in a convection oven to crosslink the imaging layer and prevent its dissolution in the subsequent underlayer develop step. The HEBR-214 samples were immersion developed in Waycoat PLSI developer (5:4) for 4 minutes. The PMMA samples were developed in MIBK developer for 1 minute. The samples were DUV flod exposed for 75 minutes and developed for 1 minute in KTI ZX-934 developer (1:1).

The resulting images were analyzed by taking SEM photographs. Scumming from interfacial layer formations, and overall image quality were observed.

RESULTS/DISCUSSION

The thermal stability studies indicated that 10 micron PMGI resist lines began to flow after a 30 minute 220C bake. No resist flow was observed at bakes up to 200C. Figure 1 shows a 10 micron PMGI line with no bake. A flat surface with some edge rounding can be observed. Figure 2 shows a 10 micron PMGI line following a 220C, 30 minute bake. There is significant rounding of the features indicating thermal flow of the resist.

When immersed in the HEBR-214 casting solvent, the PMGI did not exhibit any significant thickness loss. After one hour of immersion, the thickness loss was measured to be less than 20 angstroms on the Nanospec. This indicates that the PMGI does not readily mix with the HEBR-214 imaging layer, thus resulting in little formation of interfacial layers. The thickness loss of PMMA, a commonly used planarizing material, was examined for comparison with the PMGI. PMMA exhibited significant thickness loss in the HEBR-214 casting solvent. A thickness loss of 780 angstroms per minute was measured using the Nanospec. Figure 3 shows a comparison of thickness loss as a function of time for PMGI and PMMA.

A successful bilayer resist system was obtained using PMGI as a planarization material and HEBR-214 as an imaging layer. Analysis of the wafers exposed optically indicated that resolution below two microns was obtainable. Figure 4 shows an SEM photograph of 2 micron line/space features achieved with optical exposure of the HEBR-214 imaging layer. A flat top surface does exist on the images, but some profile rounding can be seen. The resolution obtained using optical exposure could be improved by determining the optimum exposure dose of the HEBR-214 using a focus and exposure matrix. Stepper exposures may also be investigated. E-beam exposures of the HEBR-214 on the SEM provided fair results. Large geometries of about 200 microns were investigated. Some residual resist was observed, most likely caused by incomplete exposure of the imaging layer. Higher E-beam doses may be required to attain a more reproducible process.

The PMMA/PMGI resist scheme provided a better bilayer E-beam/DUV resist system. E-beam exposure doses of 100-120 uC/cm2 with a 45 second develop in Mead PMMA developer successfully cleared the PMMA imaging layer. Following the 75 minute DUV flood exposure and aqueous develop, no residual resist was observed. This indicates that there was little interfacial layer formation. Cross-sections were not available to examine image profiles.

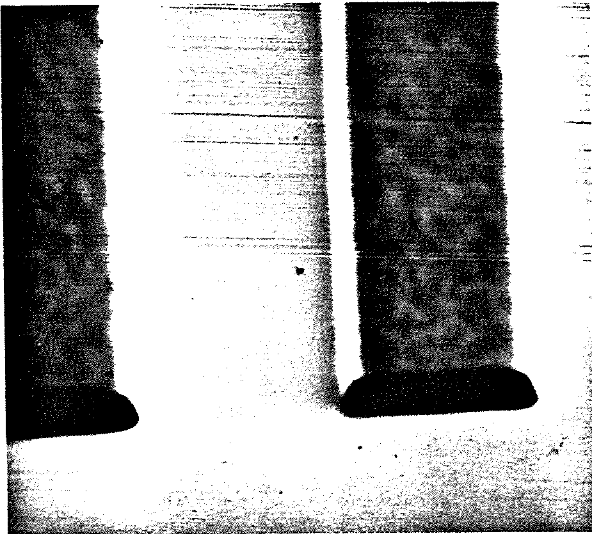

Figure 1: 10um PMGI Line
No Post Bake

Figure 2: 10um PMGI Line
200C, 30 min. Bake

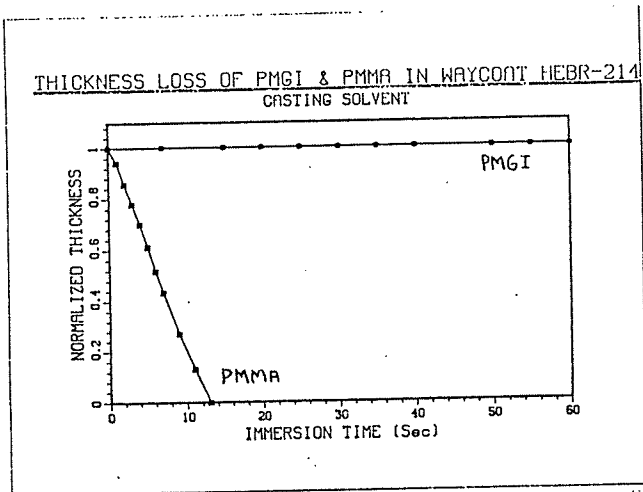

Figure 3: Thickness Loss in
Casting Solvent

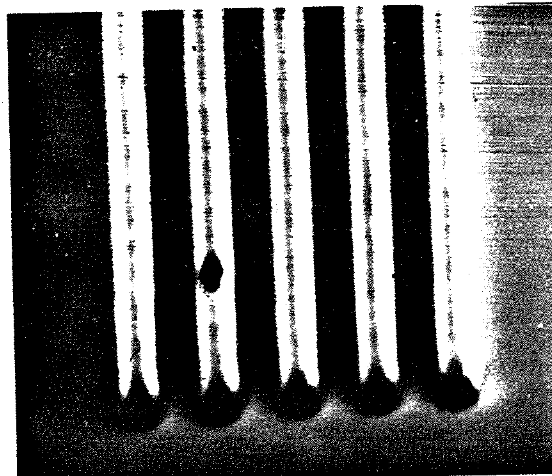

Figure 4: 2um PMGI Line/
Space Features

CONCLUSIONS

Two functioning bilayer E-beam/DUV resist systems were developed in this project. Both PMMA/PMGI and HEBR-214/PMGI resist schemes successfully demonstrated that they are compatible for electron beam applications. The PMMA/PMGI system required an E-beam exposure dose of 100-120 uC/cm2. No residual resist problems were encountered. The HEBR-214/PMGI system exhibited some scumming problems at doses of 20-40 uC/cm2. These problems could probably be eliminated with a higher E-beam exposure dose. The HEBR-214/PMGI system also proved to be a successful optical/DUV bilayer scheme. Resolution below 2 microns was obtained. The DUV flood exposure required a 75 minute exposure time due to the low DUV output of the mercury source. To improve throughput and make the process feasible, a more powerful DUV source, such as an excimer laser, is needed.

The project also verified two PMGI resist characteristics. The PMGI was found to be thermally stable up to about 220C. This makes it useful for increased temperature processing. PMGI also exhibited very low solubility in the HEBR-214 casting solvent. This indicates that little interfacial layer formation is expected when using PMGI as a planarization material in a bilayer process.

ACKNOWLEDGMENTS

I would like to thank Bruce Smith and Mike Jackson for their suggestions, advice, and help in obtaining materials. I would also like to thank Scott Blondell for his assistance with the SEM.

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