Aspect Ratio Improvement using the 2-Step NERIME FIB Top Surface Imaging Process for Nanolithography Applications

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ABSTRACT

The 2-step negative resist image by dry etching (2-step NERIME) focused ion beam (FIB) top surface imaging (TSI) process has been previously reported as an excellent technique for patterning nanometer scale features in DNQ/novolak based photoresists on silicon substrates. Previous work has demonstrated the 2-step NERIME process using 1.5µm thick films of the DNQ/novolak based resist SPR660, reporting 100nm critical dimensions (CDs) with aspect ratios of approximately 15:1. This paper demonstrates a significant improvement in aspect ratio performance of the 2-step NERIME process, yielding typical aspect ratios of 21:1 using a 1.89µm thick film of the DNQ/novolak based resist OIR-89, while retaining resist profile control at 90nm CDs. We also demonstrate that the 2-step NERIME process can be used to pattern photoresist features on different substrate materials.

Keywords: fib, nanolithography, nerime, aspect ratio, photoresist.

1 INTRODUCTION

FIB technologies are commonly used in advanced lithographic techniques to pattern small geometry integrated circuits and fabricate optical masks. A significant application for FIB technologies is the direct lithography patterning of photoresists [1], [2].

In FIB lithography, ion beams of different elements (Ga^+, H^+, He^+, Be^+, Al^+, Si^+) can be used to pattern resist by introducing energy into a resist film, followed by a wet or dry development process [3]. The introduction of energy into a resist film during ion beam lithography, by ion implantation, is similar to electron beam exposure during electron beam lithography.

FIB lithography has significant advantages over electron beam lithography, particularly in the areas of resist sensitivity, proximity and backscattering effects [2]. When comparing FIB exposure with electron beam exposure, distortions in submicron resist patterns due to resist loading effects have been found to be less significant when using FIB patterning techniques. The reduced proximity effects observed in FIB lithography are due to the fact that resist patterns exposed by ion beams are limited only by ion straggling, which has a much smaller distance associated with it than the range of scattered electrons during electron beam lithography [3]. Therefore, FIB lithography can be used to successfully pattern nanoscale resist CDs.

FIB lithography has limitations, however, such as slow writing speeds, limited penetration depth of ions into the resist film, and the possibility of substrate damage during ion beam exposure. Ga^+ ions implanted at 100keV energies into resist have typical penetration depths of approximately 50nm, and thin resist layers would be required to ensure full exposure of the resist layer during FIB lithography. Small aspect ratio features patterned using thin resist layers can cause problems for subsequent processing steps such as plasma etching, where high resist aspect ratios and high etch selectivity to resist layers are desirable.

TSI processing is a solution to the problems of thin resist layers and low aspect ratio resist features in FIB lithography. In FIB TSI schemes, the exposure does not need to penetrate the full thickness of the resist layer, but only a thin surface layer. Subsequent wet or dry processing develops away the unexposed resist, leaving only the exposed areas [4], [5]. TSI processes can overcome common lithography problems such as low depth-of-focus and substrate topography effects.

The 2-step NERIME process is a single layer FIB TSI scheme optimised for DNQ/novolak based photoresists. The 2-step NERIME process combines the advantages of FIB lithography and TSI processing, and is capable of delivering nanometer scale resist CDs [6]-[11]. The 2-step NERIME process diagram is shown in Figure 1.

The first step of the 2-step NERIME process flow is the exposure of the DNQ/novolak resist film by the implantation of Ga^+ ions. Ga^+ was chosen because of its low penetration depth in resist, and this low penetration depth is consistent with TSI requirements. The Ga^+ is implanted into the resist layer to depths of between 10-50nm. The implanted resist regions form a Ga_2O_3 mask during the oxygen plasma dry develop step of the process flow. The Ga_2O_3 regions have a much slower etch rate in oxygen plasma when compared with the unexposed resist areas. This difference in etch rates between exposed and unexposed resist areas during the oxygen dry develop step results in the formation of a negative resist image in the resist layer.

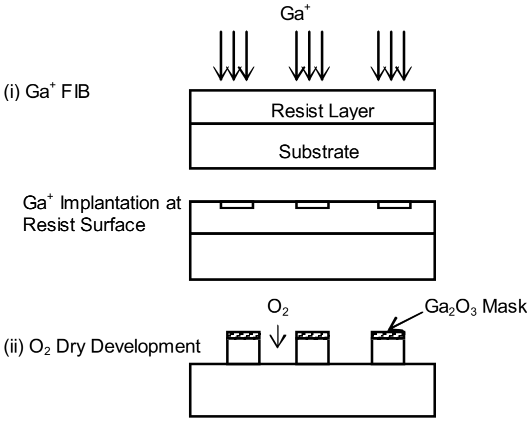

Figure 1: The 2-step NERIME process diagram, showing (i) Ga^+ FIB exposure step and (ii) oxygen plasma etch develop step.

2 ASPECT RATIO IMPROVEMENT

Previously reported work has demonstrated the 2-step NERIME process using 1.5μm thick films of the DNQ/novolak based resist SPR660, reporting 100nm CDs with aspect ratios of approximately 15:1 [8]. We show a significant improvement in aspect ratio performance of the 2-step NERIME process, yielding typical aspect ratios of 21:1 using 1.89μm thick films of the DNQ/novolak based resist OIR-89 on silicon substrates, while retaining resist profile control at 90nm CDs.

Through a series of process experiments, we optimised OIR-89 film thickness, Ga^+ ion beam dose and O_2 plasma etch parameters. A 1.89μm thick OIR-89 resist film was exposed with a Ga^+ beam dose of 1.15×10^{-2} C/cm^2, and then dry developed for 1350s in an O_2 plasma etch at 2mTorr pressure. Figures 2 and 3 show SEM micrographs of the resultant 90nm resist lines, with aspect ratios of 21:1, formed on silicon substrates using this optimised 2-step NERIME process.

Figures 2 and 3 also show well-resolved resist features with smooth sidewalls with no visible line edge roughness, a significant parameter in other TSI process schemes. The improvements in resist aspect ratio reported here are particularly significant for subsequent dry plasma etch process steps, where thicker resist layers are usually required to facilitate poor plasma etch selectivity to resist. We anticipate that our high aspect ratio nanolithography-defined resist features will be used in plasma etch definition process modules, where the increased resist thickness and narrow CDs can facilitate feature definition in the nanometer regime using conventional i-line photoresists.

Possible applications for our optimised process include nanometer MEMs, DRAM, CMOS and BiCMOS processing, or any application where high resolution high aspect ratio lithography is required over substrate topography.

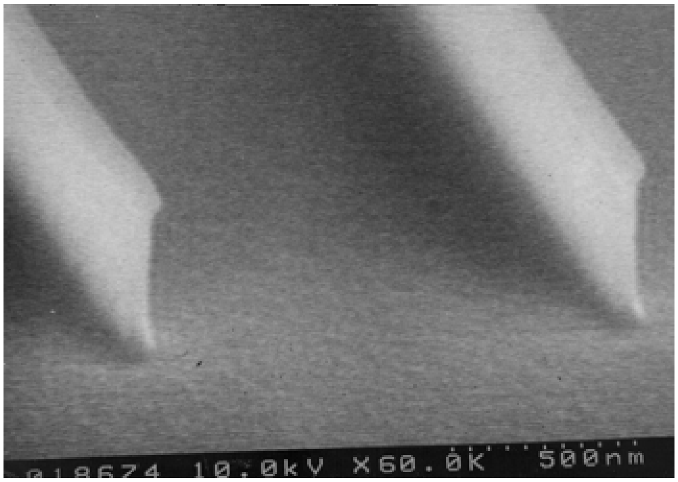

Figure 2: SEM micrograph of 90nm resist lines on silicon, with 21:1 aspect ratio, formed in 1.89μm thick OIR-89 resist using the 2-step NERIME process. The wafer received a Ga^+ beam exposure dose of 1.15×10^{-2} C/cm^2, and was dry developed for 1350s in an O_2 plasma etch at 2mTorr pressure.

Figure 3: SEM micrograph of 90nm isolated resist line on silicon, with 21:1 aspect ratio, formed in 1.89μm thick OIR-89 resist using the 2-step NERIME process. The wafer received a Ga^+ beam exposure dose of 1.15×10^{-2} C/cm^2, and was dry developed for 1350s in an O_2 plasma etch at 2mTorr pressure.

3 PATTERNING ON DIFFERENT SUBSTRATE MATERIALS

All previously reported work using the 2-step NERIME process used resist patterned on silicon substrates [6]-[11]. The ability to pattern resist on different substrate materials is an important one, particularly if a lithography scheme is to integrate successfully into a manufacturing process flow. To make the 2-step NERIME process potentially useful in nanolithography applications, it must yield acceptable CD, profile and aspect ratio results on a variety of materials commonly used in device fabrication processes. We demonstrate the 2-step NERIME process on typical substrate materials such as CVD silicon dioxide (oxide), polycrystalline silicon (polysilicon), titanium metal (Ti).

3.1 OIR-89 Resist on Oxide

We deposited 1.89μm thick films of OIR-89 resist on 4300A thick films of CVD-deposited oxide. The FIB exposure dose and oxygen plasma dry develop steps were optimised through process experiments. The wafer samples received an optimised process with a Ga^+ beam exposure dose of $1.15x10^{-2}$ C/cm^2, and a dry develop process of 1325s in an O_2 plasma etch at 2mTorr pressure. Figure 4 shows a FIB image of the resultant resist features with 13.5:1 aspect ratios and 140nm CDs. The images show well resolved resist features, with good profile control.

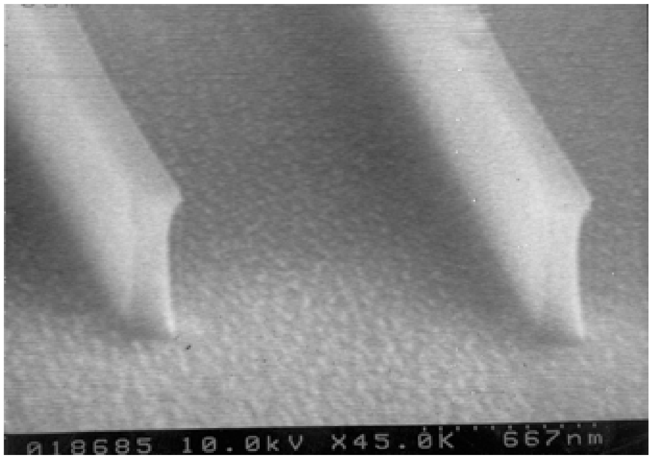

Figure 4: SEM micrograph of 140nm resist lines on oxide, with 13.5:1 aspect ratio, formed in 1.89μm thick OIR-89 resist using the 2-step NERIME process.

3.2 OIR-89 Resist on Polysilicon

We deposited 1.89μm thick films of OIR-89 resist on 3000A thick films of N^+ doped polysilicon. The FIB exposure dose and oxygen plasma dry develop steps were optimised through process experiments. The wafer samples received an optimised process with a Ga^+ beam exposure dose of $1.05x10^{-2}$ C/cm^2, and a dry develop process of 1300s in an O_2 plasma etch at 1.8mTorr pressure. Figures 5 and 6 show FIB images of the resultant resist features with 90nm and 150nm CDs, respectively. The images show well resolved resist features, with excellent profile control.

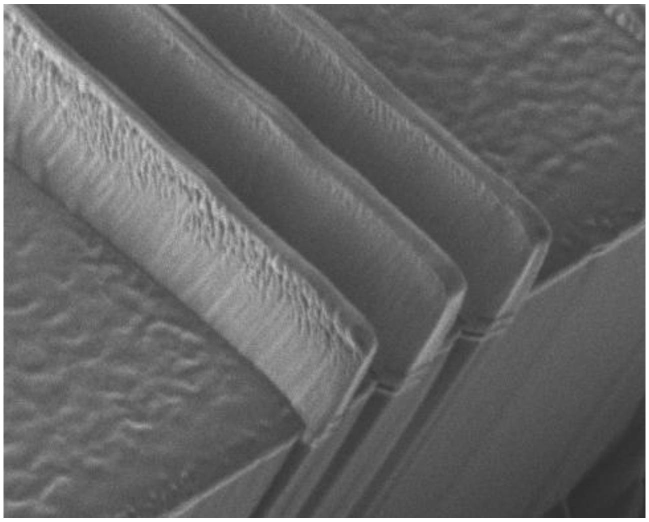

Figure 5: FIB image, tilted view, of three 90nm resist features, with 21:1 aspect ratio, formed in 1.89μm thick OIR-89 resist on 3000A thick film of N+ doped polysilicon using the 2-step NERIME process.

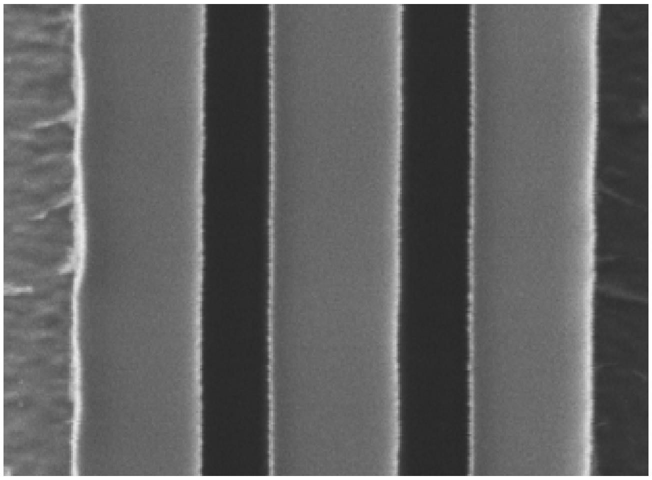

Figure 6: FIB image, plan view, of three 150nm resist features, with 12.5:1 aspect ratio, formed in 1.89μm thick OIR-89 resist on 3000A thick film of N+ doped polysilicon using the 2-step NERIME process.

3.3 OIR-89 Resist on Ti

We deposited 1.89μm thick films of OIR-89 resist on 1200A thick films of Ti. Again, we optimised the FIB exposure dose and oxygen plasma dry develop steps through process experiments. The wafer samples received an optimised NERIME process flow, using a Ga^+ beam exposure dose of $1.25x10^{-2}$ C/cm^2, and a dry develop process of 1250s in an O_2 plasma etch at 1mTorr pressure.

Figure 7 shows a FIB image of the resultant resist features with 140nm CDs. The images show well resolved resist features, with good profile control.

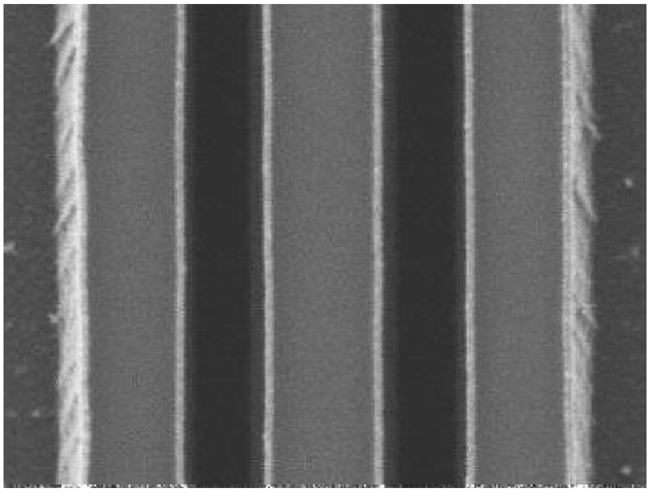

Figure 7: FIB image, plan view, of three 140nm resist features, with 13.5:1 aspect ratio, formed in 1.89μm thick OIR-89 resist on 1200A thick film of Ti using the 2-step NERIME process.

4 CONCLUSIONS

We have shown experimentally that the 2-step NERIME FIB TSI process can successfully pattern high aspect ratio nanometer resist features in DNQ/novolak based photoresists, and we report 90nm CDs with aspect ratios of 21:1 using OIR-89 photoresist.

We have demonstrated using the 2-step NERIME FIB TSI process to pattern nanometer resist features on silicon, oxide, polysilicon and Ti substrates. The improved process performance of the 2-step NERIME TSI process presented in this paper can be further extended to the sub-50nm regime. Suitable applications for this optimised process include process modules for nanoscale definition in MEMs, DRAM, CMOS and BiCMOS processing, or any application where high resolution high aspect ratio nanolithography is required over demanding substrate topography.

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