Implementation of COMA type ArF Resist for Sub-100nm Patterning

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To accomplish sub-100nm minimum feature size to sub 100nm, new light sources for photolithography are emerging, such as ArF(λ=193nm), F2(λ=157nm), EPL(E-beam Project Lithography) and EUV(Extremely Ultraviolet, χ=13nm). Among these lithography technologies, ArF lithography will be used for sub 100nm lithography at first. For a few years, ArF resist development has been the key issue for the success of ArF lithography. For this ArF lithography, we have developed COMA (cyclo-olefin/maleic anhydride) type ArF resists in which the base resin consists of cycloolefin and maleic anhydride. Now, this COMA type resist is strong candidate for primary ArF resist. From the patterning results, we can say that the ArF resist is enough to start real device production except contact hole patterning. For the sub 100nm contact hole patterning, more intensive research must be performed in the field of RFP (Resist Flow Process) or RELACS (Resolution Enhancement Lithography Assisted by Chemical Shrink). From the etch resistance point of view, COMA type ArF resists have some problems under oxide etch condition. To solve this oxide etch problem, additional E-beam curing is required. For the more fundamental solution for the oxide etch, new etch equipment or hard mask must be developed for implementation of ArF process. E-beam curing also solves the line slimming due to E-beam attack during SEM measurement.

Keywords: ArF resist, COMA(cycloolefin-maleic anhydride), Photolithography

1. Introduction

After a lot of research and development efforts, KrF DUV (λ=248nm) lithography has been successfully introduced into high volume semiconductor manufacturing for 180nm applications and is being pushed its limit down to sub-130nm regime [1-4]. For the sub-100nm feature size, new light sources for photolithography are emerging, such as ArF (λ=193nm), F2 (λ=157nm), and EUV (Extremely Ultraviolet, χ=13nm). [5] However, there is strong need for new photoresists, which are transparent to these light sources. For ArF photoresist, aromatic polymers used as a base resin for I-line(365nm) and KrF(248nm) photoresist could not be used owing to their strong absorption to 193nm. For this reason, instead of aromatic polymers, cycloaliphatic polymers or acrylate polymers that have cycloaliphatic pendant groups have been used as a base resin owing to their transparency to 193nm and etch resistance. [6-40] Among these polymers, cyclo-olefin/maleic anhydride (COMA) polymers and alicyclic pendant substituted acrylate polymers are strong candidates as base resins for 193nm resist. We have introduced feasibility of COMA type resist as a base resist for 193nm lithography and demonstrated its good properties such as resolution and etch resistance.[12-24] Now, there remain two strong candidates for the base polymer, COMA and acrylate type resists.

In this study, we will show the evaluation results of state-of-the-art of ArF photoresists for the real 120nm design rule device patterning and etching, and we also show feasibility of 100nm, and sub 100nm patterning.
2. Experimental

Materials and Process Condition

Photoresist: Commercial resist of Dongjin DHA-H110 (COMA type), Clarient AX1020P (acrylate type), and sample base Shinetsu SAIL-AH02 (COMA type), ArF resists were used. The process condition for Dongjin resist is thickness: 3000 Å, BARC; AR1 9(820 Å), soft bake; 110°C/90 sec, post exposure bake; 110°C/90 sec, exposure tool; 0.63NA, PASS5500/900 (ASML), illumination; annular (0.55/0.85), reticle; binary intensity mask, develop time; 30 sec. For the SAIL-AH02, process condition is soft bake; 130°C/90 sec, post exposure bake; 130°C/90 sec, develop time is 35 sec, and other process condition is same as Dongjin resist. For AX1020P, process condition is soft bake; 120°C/90 sec, post exposure bake; 120°C/90 sec, develop time is 35 sec, and other process condition is the same as Dongjin resist.

Bottom Anti-Reflective Coating (BARC) material: Shipley Ar19 was used as an organic BARC material. Cross linking bake temperature is 205°C/90 sec.

RELACS material; Clarient AZ R500 was used. The process condition for KrF RELACS is premixing bake; 85°C/70 sec, develop; DI water 25sec. For the ArF, premixing bake; 150°C/70 sec, develop; DI water 25sec.

E-beam curing; ElectronCure™ system from Allied Signal Inc. was used.

Etch; Unity 85DD from TEL was used. The etch condition is 1400W, 26mT, etching gas; fluorocarbon and argon, 60°C, 100 sec.

3. Results and Discussion

Figure 1 shows ultimate resolutions of ArF resists for 1:1 dense L/S pattern and isolated pattern. As we can see, using annular illumination condition, 100nm 1:1 dense L/S pattern and 70nm isolated pattern can be obtained by COMA type and acrylate type resists. At the illumination condition of 0.63NA exposure tool and annular illumination, the 100nm 1:1 L/S pattern means that kl value is 0.33. In case of KrF resist with 0.75NA exposure tool and annular illumination condition, kl value is also 0.33 because we can get 110nm L/S pattern. We can say that the ArF resist maturity is similar to KrF resist in the respect of patterning and sub-100nm real process will be possible if we use high NA scanner more than 0.75NA. Figure 2 shows 100nm 1:1 dense L/S pattern obtained using dipole(0.55/0.85, 30 degree open) illumination. The depth of focus is 0.8μm.

Figure 3–5 show real device patterns obtained with liquid phase amine gradient process. [16] The reason for 120nm patterning is that we have only 120nm full set mask. 1:1 island pattern (landing plug), 120nm 1:1 contact pattern (storage node), and 120nm 1:1 line and space pattern (word line) could be obtained with ASML ArF Scanner PAS/900(0.63NA) using annular (0.55/0.85) off-axis illumination. The process margin and pattern fidelity are enough to fabricate real device in the viewpoint of patterning. Figure 6 is the etch results of critical layers of 120nm design rule device.
isolation, (b) gate line, (d) bit line, and (e) storage node masks can be etched easily by conventional method but in case of (c) landing plug layer, it cannot be etched by normal etch process. Landing plug etch result was obtained with additional process, E-beam curing, and we will discuss the etch result of landing plug oxide layer at later section.

As shown in figure 7, using dipole illumination condition, we can get 90nm L/S patterns. The exposure latitude is 8.4% and depth of focus is 0.3µm. 90nm L/S pattern means that the k1 value is 0.29 when we use dipole illumination condition. Figure 8 is the CD linearity of DHA-H110 using dipole illumination. CD is linear to 100nm dense 1:1 L/S pattern. From this results, we can confirm that the 100nm design rule device can be developed with 0.63NA Scanner with dipole illumination.
illumination condition. Gate line of 66nm can be obtained with 0.60NA and conventional illumination as shown in figure 9 but there is some loss of resist thickness as the pattern size decreases. Using this isolated line, we can fabricate 70nm transistor.

In case of contact hole patterning, ArF resist needs more research. In DRAM fabrication, the required contact hole size is similar to half pitch of L/S pattern. But the lower capability to define contact hole than L/S pattern requires additional process such as resist flow process [41–43] or RELACS [44, 45] process. In case of KrF resists, there are many resists that can be shrunk from...
In addition to there is RELACS material for contact hole shrink as figure 10(b). But in case of ArF resist there is no resist for contact hole RFP and only 30nm contact hole shrink was possible from 140 to 110nm with RELACS process with COMA type resist as shown in figure 10(c). Acrylate type resist could not be used because it did not work with RELACS materials. So we have no choice but to use KrF RFP for 100nm contact hole patterning. Though KrF RFP and RELACS process is possible for 100nm real device application, sub 100nm is not easy. The reason is that there is no plenty of resist volume for flow on the vicinity of contact hole when the contact hole shrinks severely. So, more researches must be concentrated on developing ArF RFP and RELACS resists.

ArF resists have similar etch resistance at poly etch condition but they show poor etch resistance under oxide etch conditions. Oxide etch results of KrF, acrylate type ArF resist, and COMA type resist

200nm to 100nm figure 10(a). [43] In addition to there is RELACS material for contact hole shrink as figure 10(b). But in case of ArF resist there is no resist for contact hole RFP and only 30nm contact hole shrink was possible from 140 to 110nm with RELACS process with COMA type resist as shown in figure 10(c). Acrylate type resist could not be used because it did not work with RELACS materials. So we have no choice but to use KrF RFP for 100nm contact hole patterning. Though KrF RFP and RELACS process is possible for 100nm real device application, sub 100nm is not easy. The reason is that there is no plenty of resist volume for flow on the vicinity of contact hole when the contact hole shrinks severely. So, more researches must be concentrated on developing ArF RFP and RELACS resists.

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are shown in figure 11. To compare with KrF resist, ArF resists show severe striation. The exact cause of this striation cannot be understood yet. Though the COMA type resist shows better oxide etch resistance than acrylate type resist but it does not have enough etch resistance for real device application. To solve this striation problems, we conducted E-beam curing experiment. After E-beam curing of island pattern (landing plug) with 2000μC/cm², the pattern fidelity of etched layer improved. But E-beam curing requires 10 min/wafer, so considering throughput, E-beam curing method is not suitable for real device production. To minimize E-beam curing time, we conducted dose split test. As shown in figure 12, COMA resist requires 400mC/cm² that means only 2 minute/wafer. In case of acrylate type resist, it requires at least 2000mC/cm² as shown in figure
12. Any etch recipe tuning such as power, temperature, and gas pressure to solve striation did not give any solution. So new etch equipment or hard mask must be developed for implementation of ArF Process.

Line slimming problem is another issue of ArF photoresist, so many researches have been conducted in this field. This line slimming problems also can be solved by E-beam curing method. Without E-beam curing the line slimming is 12nm in case of 120nm L/S pattern. But this slimming decreased to 6nm with 400mC/cm² dose and after 1600mC/cm² dose it decreased to only 2nm.

IV. Conclusions

In this paper, we showed that the k1 value of COMA and acrylate type resist were about 0.33 which was same as the KrF resist under the annular (0.55/0.85) illumination condition. Using dipole illumination (0.55/0.85) and 30 degree open, we obtained a 90nm 1:1 L/S pattern, which means that the k1 values is 0.29. In patterning, now the ArF resists are enough to start real device production except contact hole patterning. For the 100nm contact hole patterning, until now, the unique solution is KrF RFP or RELACS. For the sub-100nm contact patterning, ArF resists for RFP and RELACS must be developed. Unlike the KrF resist, ArF resists have some problems in oxide etch resistance. In oxide etch resistance, COMA has better properties than acrylate type resist but in both case, additional E-beam curing was required for real device production. As the base polymer of resist is either COMA or acrylate type, it is not easy to solve oxide etch resistance by resist modification. So the development of new etch equipment or hard mask will be a key solution.

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References


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