Dry Development Rinse Process (DDRP) & Materials (DDRM) For EUVL

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EUV lithography has been desired as the leading technology for single nm half-pitch patterning. However, the source power, masks and resist materials still have critical issues for mass production. Especially in resist materials, RLS trade-off is the key issue. To overcome this issue, we are suggesting Dry Development Rinse Process (DDRP) & Materials (DDRM) as the pattern collapse mitigation approach. This DDRM can perform not only as pattern collapse free materials for fine pitch, but also as the etching hard mask against bottom layer (spin on carbon: SOC). In this paper, we especially propose new approaches to achieve high resolution around hp10nm. The key points of our concepts are 1) control PR profiles, 2) new solvent system to avoid chemical mixture, 3) high etching selective DDR materials and 4) high planar DDR materials. This new DDRM technology can be the promising approach for hp10nm level patterning in N7/N5 and beyond.

Keywords: EUV, photo resist, DDR, under layer, PTD, Si-HM, SOC, etching

1. Introduction

EUV lithography has been desired as the leading technology for below Hp20nm. However, the source power, masks and resist materials still have critical issues for mass production. Especially in resist materials, RLS (Resolution, Line edge roughness and Sensitivity) trade-off is the key issue for EUV lithography. To overcome this issue, we have succeeded to develop organic type resist under layer (UL) from the much knowledge of Anti-Reflective coating (ARC) material. The UL can reduce RLS trade-off issue for single layer process and it is used with CVD-HM for device manufacturing [1-4]. On the other hand, Tri Layer process with spin on hard mask materials is another candidate process. The advantage point of Tri layer process is cost reduction and rapid manufacturing compared to CVD-HM process. We, Nissan Chemical, have been vigorously developed spin on hard mask such as Si-HM and SOC [5].

However, in the most advanced devices like N5 and beyond, Tri-layer system would be suffered severe etching issues. One of the issues is etching

pattern transfer failure due to too low etching selective and thin PR (vs Si-HM). In recent technology, PR should be thinner and thinner because of the prevention of pattern collapse. To overcome these expected issues, Si reverse process is recently focused strongly [6]. One of the advantage points of Si-reverse process is that thicker Si reverse materials can be applied to achieve enough etching selectivity. It means that it is not necessary to take care about the etching selectivity of PR. It would be happy for the development of PR materials. The other advantages of Si-reverse process are that a thicker Si material is easy to pattern transfer to SOC and it is also low cost process same with normal Tri-layer system.

Dry Development Rinse Process (DDRP) (Figure 1) is very similar process with Si-reverse process except coating Si materials (DDRM) after development and rinse [7,8]. One of the biggest advantage points in DDRP is to prevent pattern collapse perfectly because its capillary force never happens. This DDRP is already one of the strong

candidate processes in fine pitch process like from 20 to 40nm pitches patterning. However, DDRP has never reached to below hp10nm L/S. In this paper, at first the limitation of current DDRP and DDRM was investigated and confirmed. Then some of new ideas to break the limitation were proposed. Finally new DDRM was developed to solve current issues and demonstrated with EUV scanner.

Figure 1. Tri-layer scheme, Si reverse process and DDRP.

2. Experimental

2.1. Material

We developed and used DDR materials for DDR process. DDR materials are categorized two types, one is for current std. DDRM containing 30% alcohol to get high solubility and stability. The other is new DDRM which is 100% water solvent system. The detail of DDR material design is summarized in Table 1.

Table 1. DDR material designs.

Generation		Std. DDRM	New DDRM
Target hp		>10nm	Single nm
Application		For PTD	
Polymer
Solvent		Water base (with alcohol)	Water [100]
Mechanism
Etching Rate (vs. P.R.)	By CF4 gas	1.4	1.4
	By O2 gas	<0.10	<0.08
Planarity		Normal	Better (Low shrink)

2.2. Lithography

DDR process is applicable to most of lithography process such as ArF-extended, EUV, EB, DSA and so on. In this paper, we investigated DDR process by EB and EUV lithography process. EB was carried out on a JEOL JFX6300 and Elionix ELS-125F as exposure tool. EUV lithography was carried out on a NXE3300B (NA: 0.33) as exposure tool, and TEL CLEAN TRACK Lithius ProZ as coater and developer. In both case, EUV UL was coated on bare silicon wafer and baked at 205 °C for 60 seconds to obtain the thin film in 5 to 20 nm film thickness. EUV photo resists were coated, exposed and post-exposure-baked at the recommended conditions. Then photo resists were developed for 30 seconds by 2.38% TMAH developer and rinsed for 15 seconds by de-ionized water. Finally, DDR material was dispensed during DI water spin drying step.

2.3 Etching

DDR material and PR materials were etched by Reactive Ion Etching (RIE) system. The etching conditions were shown as follows. The etching chamber was conductive chamber.

[Etching condition: Etching back (recess etching)
DDR material]

Gas: CF₄=50 sccm, Ar=200 sccm,
RF-power=200W, Pressure=10mT

[Etching condition: PR removal]

Gas: O₂=150 sccm N₂=50 sccm, RF-power=300W,
Pressure=10mT

3. Results and Discussion

3.1. Consideration of the resolution improvement

DDRP was investigated with Hp 15nm L/S, Hp12nm L/S and Hp10nm L/S pattern with EUV interference exposure tool at PSI. In Hp15nm L/S, undercut and top loss profile of DDR pattern was observed. This undercut profile would be caused by PR profile and top loss profile would be obtained by chemical mixing between PR and DDRM. At first topic, we will discuss which PR profile is the best. Then, we will focus on the change of solvent system to prevent chemical mixing. In Hp12nm L/S, high wiggling DDR pattern was observed. This phenomenon was generally come from poor etching resistance and high mobility of DDR pattern during dry etching. In third topic, we will demonstrate DDRP with high and low etching resistance of DDRM. In Hp10nm L/S, extremely low contrast DDR pattern

was found. This low contrast DDR pattern was mainly caused by low planarity of DDRM. For example, if the planarity of DDRM was poor, longer etch back time is necessary. The aspect ratio of final DDR pattern was low. On the other hand, if the planarity of DDRM was high, longer etch back time is NOT necessary. The aspect ratio of final DDR pattern was relatively high. In 4th topic, we will investigate the planarity evaluation from the view point of material (Fig. 2).

Figure 2. Consideration and New concepts for single nm resolution.

3.2. Control of DDR pattern profile

In first topic, we will consider to control of DDR profile. In Table 2, the relationship between PR and DDR pattern profile. This PR and DDR patterning was demonstrated with EB lithography. In top rounding and footing PR profile which is normal in EUV, DDR pattern showed totally opposite T-top or undercut profile. In straight type PR profile, final DDR pattern was also almost straight and LWR was over 3 nm. In under taper type PR profile which already collapsed, DDR pattern showed taper profile with 2.8 nm in LWR. Especially in under taper and thicker type PR profile, final DDR pattern showed high aspect ratio and taper profile. From LWR results, final thicker and taper type profile showed the best. In order to achieve better LWR parameter, taper and thicker type DDR should be the best.

Table 2. The relationship between PR profile & DDR profile.

* EB lithography demonstration				
PR profile	Top rounding Footing	Straight	Under taper	Under taper & Thicker PR
LWR	-	2.6nm	Collapse	Collapse
DDR Profile	T-top Under cut	Straight	Taper	Taper High A.R.
LWR	⊗	3.2nm	⊙ 2.8nm	⊙⊙ 2.4nm

Next, we focused the profile of DDRM bottom layer which was organic UL. Especially, organic UL showed severe undercut profile due to side etching damage from dry O₂ type etching. In this time, we substituted from Organic UL to Spin on Carbon (SOC) layer and investigate DDR patterning with excess O₂ etching condition. As this result, even hp27nm L/S was totally collapsed due to severe etching damage of Organic UL, but hp18nm L/S finally obtained with SOC layer (Fig.3). This suggested SOC can resist even severe etching condition and SOC has possibility to improve resolution more and more.

Figure 3. DDR patterning with organic UL and SOC as bottom layer.

3.3. Investigation of 100% water solvent system

Next topic, new solvent system which was 100% water solvent was investigated to prevent from chemical damage from PR. Current normal DDRM contains some of alcohol to achieve high stability and solubility. However, these kinds of alcohol should migrate to PR and finally chemical mixing was happened between PR and DDR pattern interface. In order to prevent this type damage, 100% water solvent system was investigated.

At first, the mixing level between PR and DDRM was analyzed by TOF-SIMS. In this TOF-SIMS analysis method, Si atom intensity was monitored from the DDRM surface to substrate vertically. As the results, mixing layer was observed in PR layer. The mixing level of std. DDRM containing alcohol as the solvent was much wider than new DDRM containing no alcohol. Moreover the slope of std. DDRM is lower than new DDRM. This also indicated chemical damage of new DDRM is limited because Si atom migration to PR film is lower than std. DDRM (Fig. 4).

Figure 4. Analyzed film stack and results by TOF-SIMS.

Next Hp22nm L/S was demonstrated with DDRP in EB lithography. In Std. DDRM containing alcohol, Hp22nm L/S was partially obtained and LWR was 4.3nm. On the other hand, New DDRM gave the perfect resolved pattern in Hp22nm L/S. LWR of new DDRM is also much better than Std. DDRM. This indicated that 100% DIW type DDRM can prevent chemical damage from PR (Fig. 5).

***EB lithography demonstration**

Figure 5. DDRP demonstration results of std. and new DDRM.

3.4 High Si% & High rigid DDRM

In third topic, DDRP with EB lithography was evaluated with low etching resistance and flexible DDRM and high etching resistance and rigid DDRM. In this evaluation, Si % of DDRM was controlled. In low Si % and flexible type DDRM,

not only Hp22nm L/S but also Hp26nm L/S didn't resolve and showed many bridges. These bridges should come from high mobility of DDRM polymer and severe physical & chemical damage during dry etching. On the other hand, high Si % and rigid DDRM showed higher resolution to Hp22nm L/S clearly. It is suggested high etching resistance and wiggling resistance gives high resolution in DDRP (Fig. 6).

***EB lithography demonstration**

Figure 6. DDRP demonstration results of Low Si and High Si type DDRM.

3.5. Planarity evaluation

Next planarity of DDRM was evaluated on PR pattern from dense pattern to open area. Planarity is also important factor to achieve high resolution as we described in chapter 3.1. In this evaluation, high shrink type and low shrink type DDRM was prepared in advance. As the results, high shrink type DDRM especially showed rounding profile on dense PR pattern. The FTK difference between on PR and on substrate is almost 8 nm. On the other hand, low shrink type DDRM showed high planarity in every pitch (dense, iso pattern and open area). The FTK difference is around 2.5 nm. This indicated low shrink DDRM showed high planarity (Fig. 7).

Figure 7. Planarity evaluation results of high shrink and low shrink type DDRM.

3.6. Patterning demonstration of new generation DDRM with EB and EUV

Initially Hp35nm L/S and Hp26nm L/S were evaluated with current DDRM and new DDRM in EB lithography. In Hp35nm L/S, both DDRM showed perfect patterning with 2.3 aspect ratio. In Hp26nm L/S, current DDRM showed pattern bridge due to flexible polymer structure. In fine pitch evaluation below 30nm L/S, aspect ratio is over 3.0 and flexible polymer of DDRM showed wiggling pattern (Fig. 8).

Figure 8. DDRP demonstration results of std. and new DDRM.

Next Hp30nm, 26nm, 22nm and 19nm dense pillar pattern were evaluated with both DDRM. At first dense C/H pattern was prepared by EB lithography. Finally dense pillar pattern was created by applying DDRP. From Hp30nm to Hp22nm, perfect dense pillar patterning was achieved. Especially, Hp19nm pillar patterning, DDR pattern was partially bridged, but not collapsed. It strongly indicated new DDRM has much potential to resolve Hp 1Xnm patterning (Fig. 9).

Figure 9. Pillar patterning with new DDRM.

At last, we investigated DDR patterning with EUV scanner (NXE3300B). New DDRM showed extremely high resolution. Finally hp 13nm L/S was perfectly obtained. The DDR patterning profile also showed straight or slightly footing. It is revealed that DDRM has much potential to improve resolution (Fig. 10).

New DDRM performance (L/S)

***EUV lithography (NXE3300B) demonstration**
New DDRM / New PR B for DDRP / Org. UL

Figure 10. hp13nm to 18nm L/S patterning with DDRP.

4. Conclusion

New DDRM was developed to achieve hp single nm resolution. The concept of DDRM development is to 1) control PR profile, 2) Prevent chemical mixing, 3) increase etching resistance and 4) get high planarity. Finally high Si% and low shrink ability with 100% water solvent system was applied to DDRM development. New DDRM showed high resolution with 13nm L/S and 20nm Pillar patterning in EUV and EB lithography. This new DDRM technology can be the promising approach for hp10nm level patterning in N7/N5 and beyond.

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