

AZ[®] 15nXT Photoresist for Lift-off Applications

CHEN Chun-wei^{*}, TOUKHY Medhat, BOGUSZ Zachary, MEYER Stephen,

LIU Wei-hong, LU Ping-hung

(AZ Electronic Materials USA Corp. (A Subsidiary of Merck KGaA, Darmstadt, Germany),

70 Meister Avenue, Somerville, NJ 08876, USA)

Abstract: AZ[®] 15nXT is a chemically-amplified negative-tone thick film photoresist. The resist has vertical profile and is widely used for redistribution layer (RDL) and through silicon vias (TSV) applications. For lift-off applications, however, the inverted profile is needed. In this paper, we report the effects of process conditions on the resist profile and process window for lift off applications.

Key words: Chemically amplified; Thick film; Lift-off; Negative photoresist; Inverted profile

1 Introduction

Patterning structures in deposited metal layers usually requires an etching (subtractive) process. In some cases such process can damage other part of the device. The lift-off process offers an alternative solution^[1]. Negative resists are generally a better choice for lift-off processes. They offer simpler, single resist coating process than positive resist lift-off process which usually requires two different coatings. An additional bottom coating of carefully controlled dissolution rate polymer is required to produce the desired lift-off undercut profile. Other lift-off positive resist process known as “the soak” process requires a developer soak and flood exposure to obtain extended resist (overhang) suitable for lift-off. The inverted or “retrograded” profiles produced by the negative resist help protecting (or shadowing) the resist sidewalls from being coated with the sputtered metal.

AZ[®] 15nXT is a chemically amplified negative tone, thick film resist, developed primarily for electroplating applications for up to 15 μ m thickness range. Chemically amplified resists can be sensitive to trace acids or bases in the atmosphere or on different substrates. AZ[®] 15nXT, however, is environmentally stable^[2], compatible with different types of substrates, particularly with Cu substrates^[3,4] and most redistribution plating solutions. This resist produces vertical profiles under optimum conditions and is widely used for redistribution layer (RDL) and through silicon vias (TSV) applications.

It is demonstrated in this paper that AZ[®] 15nXT can also produce reliable inverted profiles suitable for the lift-off process. The process conditions and lithographic parameters were optimized to achieve inverted side wall profiles. Suss aligner and ASML stepper were used to expose the resist layers and SEM observation was used to evaluate the resist profiles. The photospeed, resolution and process margin were systematically studied.

2 Experimental

2.1 Lithography equipment

Suss MA200 aligner utilizing broadband UV exposure wavelength range: 364~436nm (g, h and i

line) and ASML i-line stepper were used to expose the resist. The gap between the resist and the mask was optimized for best profiles using Suss contact aligner. Similarly, the optimum focus was determined when ASML stepper was used for best results. Suss ACS300 and OptiTrac tracks were used to coat, bake and develop the resist. Processed wafers were cleaved and cross-sectional images were taken on Hitachi S4000, S4700 and Amray 4200L electron microscopes.

2.2 Resist processing

2.2a Coating substrates and surface treatment

Most coating substrates used in this work were 6" and 8" diameter Si wafers. All Si wafers were bake dehydrated and hexamethyldisilazane (HMDS) primed.

2.2b Resist coating

AZ® 15nXT (450 CPS) was used to achieve 8~10μm film thickness by single coat. The resist coating was carried out on standard spin coaters/tracks using up to 120 second soft bake (SB) in contact at 110°C as a standard process for 8~10μm thick resist films. Film thickness (FT) and coating uniformity were analyzed with Foothill KT-22 measurement system. SB time was adjusted from 60 seconds to 180 seconds.

2.3 Exposure

The imaging of resist was carried out on a variety of exposure tools: ASML i-line stepper (ASML 0.48 NA 0.90σ) and Suss MA200 aligner (20μm proximity exposure gap).

2.4 Post exposure bake (PEB)

8~10μm thick coatings were post exposure baked (PEB) for 60 seconds in contact. Different PEB temperatures in the range of 110°C to 120°C were tested for 60 seconds.

2.5 Development

AZ® 300-MIF developer 0.26 N aqueous TMAH was used in puddle mode to develop the resist. Extended DI water rinse for at least 60 seconds is necessary to remove all unexposed resist. At least a total of 120 seconds is necessary to develop 8μm thick resist. Extended development of 1x120 second spray/puddle, 2×60 seconds and 4×60 seconds spray/puddles were used.

2.6 Design of experiments (DOE)

A three variable, 16 unique trials ECHIP-V6 statistical design was carried out with one repeat. The positions of the experimental points of the design are shown in Figure 1. Trials 17 to 21 were added later to augment the original design. The additional points allowed greater accuracy and flexibility of the mathematical analysis models. The design objective, as shown in Table 1, was to study the process conditions required to obtain a suitable lift-off profile. Furthermore, a stable process condition was optimized to achieve isolated trenches measuring: top=7μm; bottom=8μm in 8μm resist thickness, using 7μm mask. These most critical variables and their limits were determined based on earlier screening of the total process to be:

- (1) Soft bake (SB) time: 110°C for 60, 120 and 180 seconds;
- (2) Post exposure bake (PEB) temperature: 110, 115 and 120°C for 60 seconds;
- (3) Development (DEV) time: 120, 140 and 160 seconds.

3 Results and discussion

3.1 Lift-off process by using negative photoresists

The lift-off process is an efficient way of performing a blanket metal deposition across the entire

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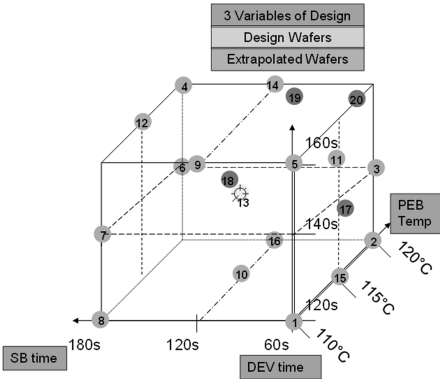


Figure 1 Design of experiment (DOE): All wafers are numbered and their coordinates on the cube indicate the conditions. The 3 variables are listed in the boxes, soft bake (SB) time, PEB temperature and development (DEV) time.

wafer that utilizes the inverted profile of the patterned resist. Negative resists are generally a better

Table 1 The process experimental design, based on a quadratic model of 16 original trials with three variables and three limits for each variable and 5 more samples added.

Trial No.	SB Time (sec)	PEB Temp. /°C	Dev. Time (Sec)
7	180	110	140
2	60	120	120
1	60	110	120
9	120	110	160
6	180	120	140
8	180	110	120
5	60	110	160
4	180	120	160
11	60	115	150
15	60	115	120
10	120	115	120
12	180	115	160
1	60	110	120
3	60	120	140
14	120	120	160
13	120	115	140
16	120	120	120
17 *	80	117	126
18 *	140	116	145
19 *	100	117	160
20 *	60	118	160
21 *	120	117	240

* Added experimental point.

choice for lift-off processes. They offer a simple, single resist coating compared to positive resist lift-off process which usually requires two different coatings. The inverted or“retrograded” profiles produced by the negative resist help protecting (or shadowing) the resist sidewalls from being coated with the

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sputtered metal. A small gap between the resist side walls and the deposited metal structures is formed during the sputtering process, as shown in the Figure 2. At the end of the process, the resist coating along with the sputtered surface metal layer can be removed with solvents leaving the patterned metal in direct contact with the substrate.

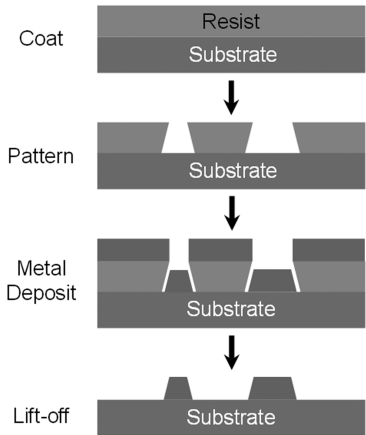


Figure 2 The lift-off process by using a negative tone photoresist

Control of line width deposition is most critical in the production and applications current and future micro technologies, such as Micro-Electro-Mechanical Systems (MEMS), giant magnetoresistive (GMR) sensor, T-gates and other microelectronic applications^[5,6].

Traditional negative tone resists are optimized to be highly transparent. Conversely, Lift-off negative tone resists achieve their inverted profile, as seen in Figure 3, by encompassing light absorbing materials into the formulation. This produces a system where by less light penetrates the full thickness of the resist compared to the resist surface, resulting in an inverted profile. AZ® nLOF 2000 resist product series is widely used for 1~20 μ m film thicknesses range, stable submicron lift-off processes^[7].

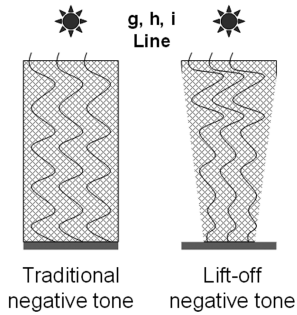


Figure 3 Illustration of traditional negative tone and lift-off negative tone resists

AZ® 15nXT is a chemically-amplified negative-tone thick film photoresist. The resist has vertical profile and is widely used for redistribution layer (RDL) and through silicon vias (TSV) applications^[3,4]. In order to achieve the inverted profile of 15nXT, one approach is to change the formulation by using light absorbing materials. Without formulation change, however, we investigate different process variables, i. e. exposure tool, soft bake (SB), exposure dose, post exposure bake (PEB) and development (Dev) conditions, for resist profile manipulation.

3.2 Lithographic performance on Suss aligner

All wafers, according to the DOE shown in Figure 1, were exposed using Suss aligner with a 20 μ m 10.14028/j.cnki.1003-3726.2014.12.020

exposure gap. The results of the experimental design were represented by the following measured responses:

- (1) The dose to achieve 7 μ m isolated trench top opening;
- (2) The dose to achieve 8 μ m isolated trenches bottom opening.

The two responses directly relate to the changes in resist photospeed as a function of the process variables. Plots of these responses, best fitted to a quadratic ECHIP model, are presented in Figures 4. Eight contour dose plots relating PEB temperature and SB time are shown in Figure 4. The top 4 plots show the doses needed to achieve 7 μ m trench top opening and the bottom 4 plots to open 8 μ m trench bottom by using 7 μ m mask in 8 μ m resist thickness. Each plot represents a single development (Dev) time: 120sec, 140sec, 160sec or 240sec.

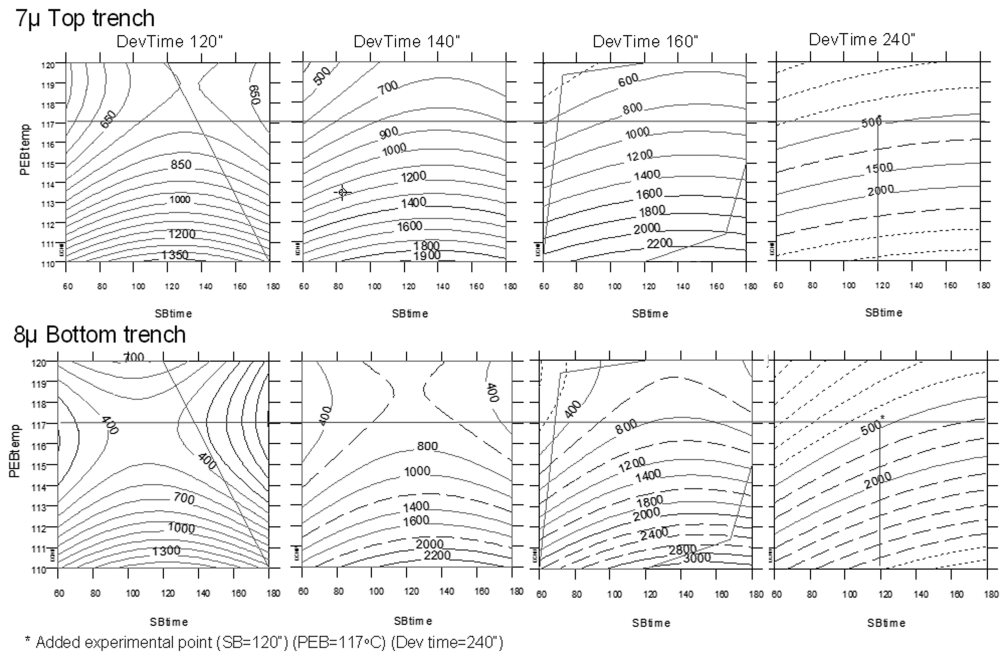


Figure 4 DOE quadratic output model; dose contour plots of SB time vs. PEB temperature. Two sets of exposure dose (mJ/cm²) contours, top and bottom, for required dose to achieve top and bottom CD target. Development times are fixed at 120, 140, 160 and 240 seconds for each set.

PEB temperature was found to be the most effective variable in controlling resist photospeed and sidewall slope. When the PEB temperature changes at a given SB and Dev time, the dose will change; the higher PEB temperature, the less dose needed. At a given PEB temperature and Dev time, the dose increases with increasing SB time.

The optimum process conditions are defined by the process area in which dose overlap (same dose) occurs between the top and bottom trench CD targets. That is, the same process area of the two sets of graphs (top and bottom plots of Figure 4) having the same contour dose values. Under such conditions the target top and bottom trench openings can be produced at the same dose. The larger the areas between the plots of the two sets (top and bottom trench CD) overlap, the more robust the process is.

Reduced PEB temperature below 120°C introduces significant retrograde profiles. Optimum PEB temperature of 117°C provided better control of isolated trench CD as well as adequate retrograde profile angles. The desired CD targets were achieved in 350~500mJ/cm² dose range by shortening the soft bake time to 120 seconds and extending the development times to 240 seconds. The area of dose overlap

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also increased as the development time was increased, providing a more robust and stable lift-off process. This was confirmed by the results of experimental point No. 21: (SB time 120”) (PEB 117℃) (Dev time 240”). The contour dose values for 7μm top and 8μm bottom trenches were 450 and 410mJ/cm², respectively.

The retrograded profiles are mainly the result of three factors: (1) resist absorption, (2) slightly more focused top image than bottom, due to exposure gap and (3) chemical enhancement of resist crosslinking as a function of PEB.

The application of 20μm gap acts as a slight defocus for the optical image, resulting in the formation of a slightly defocused image with reduced intensity and more scattering at the resist bottom (substrate) than at the resist surface. The enhanced chemical crosslinking during PEB further magnifies the optical intensity difference between resist top image and bottom to produce a greater difference between resist top and bottom CD.

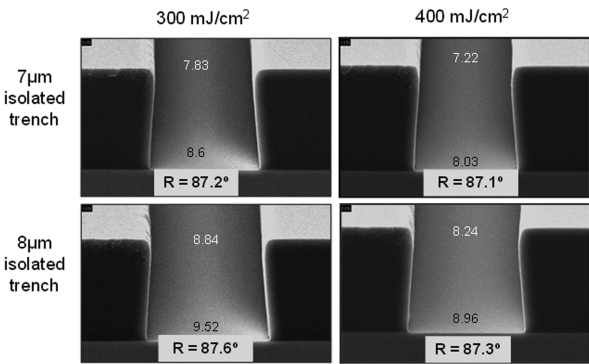


Figure 5 Full wafer confirmation data on Si wafer (R=retrograde angle). Process conditions: FT=8μm, SB: 110℃/120 seconds; PEB: 117℃/90 seconds contact; DEV: 4x60 seconds spray/puddle; Exposure: Suss broadband aligner, 20μm exposure gap.

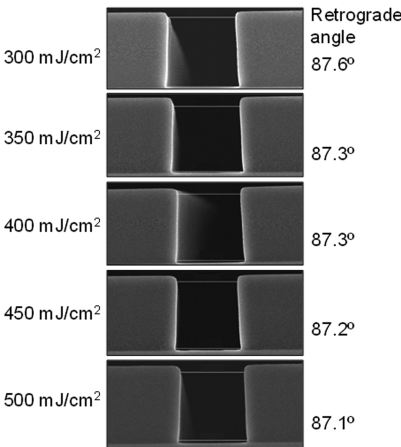


Figure 6 Exposure latitude of 8μm isolated trench on Si wafer. Process conditions: FT=8μm; SB: 110℃/120 seconds; PEB: 117℃/90 seconds contact; DEV: 4×60 seconds spray/puddle; Exposure: Suss broadband aligner, 20μm exposure gap.

Examples of the resist profiles and measured responses are shown in Figure 5. In order to reduce the dose and achieve the target inverted profile, the PEB of 117℃ for 90 seconds was applied. Extending the development time to 240 seconds was selected experimentally to obtain a more practical dose overlap. The retrograde angle for the 7μm isolated trench is 87.2° and 87.1°, for 300 and 400mJ/

cm², respectively. The exposure latitude of 8μm isolated trench is shown in Figure 6. The retrograde angle decreased slightly with increasing dose. The angle was 87.6° at 300mJ/cm² and 87.1° at 500mJ/cm². The values of the top and bottom openings of 8μm isolated trench were plotted with exposure dose in Figure 7. The two lines representing the top and bottom openings were very close to being parallel. CD control can be achieved without significantly changing retrograde profile angle by adjusting exposure dose (350~500mJ/cm²).

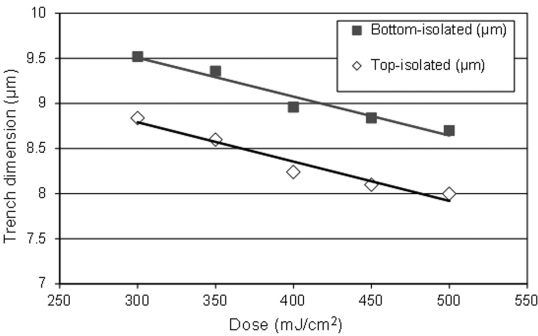


Figure 7 Top and Bottom CD of an isolated 8μm trench on Si substrate. Process conditions: FT=8μm; SB: 110℃/120 seconds; PEB: 117℃/90 seconds contact; DEV: 4×60 seconds spray/puddle; Exposure: Suss broadband aligner, 20μm exposure gap.

3.3 Lithographic performance on ASML stepper

The process latitude of 15nXT was also studied on ASML stepper by changing the focus from -1.5μm to 6.0μm. Figure 8 shows the cross section images of 5μm isolated trench in 10μm thick resist with an exposure dose of 350mJ/cm². The -1.5μm focus offset shows wider top opening while the 6.5μm focus offset shows targeted inverted sidewall profile.

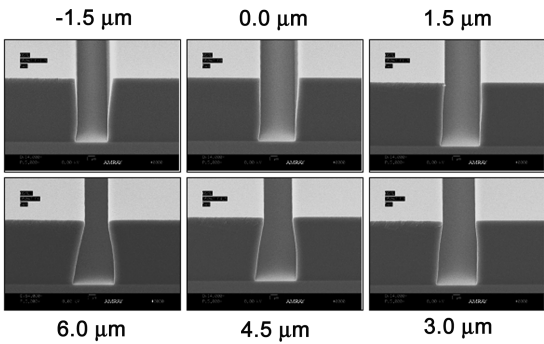


Figure 8 Depth of focus for 5μm isolated trenches on Si wafer: Process conditions: FT=10μm; SB: 110℃/120 seconds; Exposed on ASML, 350mJ/cm², PEB: 115℃/100 seconds contact; DEV: 4x60 seconds spray/puddle.

Exposing the resist with stepper focused optical system produce a greater difference in image intensity and defocus between resist top surface and bottom than when using collimated contact exposure. High numerical aperture (NA) lenses enhance image focus and resolution proportionally, however they also deteriorate depth of focus inversely to (NA)². This significantly affects the optical intensity through the resist depth. Similar explanation for the formation of inverted profile can be given here as discussed in the case of contact printing. In our experiments a +6μm defocus shift produced significant retrograded profiles as seen in Figures 8 and 9 using ASML stepper.

The resist showed wide exposure latitude from 250 to 450mJ/cm² at the focus offset of 6μm, as shown in Figure 9. The top and bottom opening distances of 5μm isolated trench were plotted with

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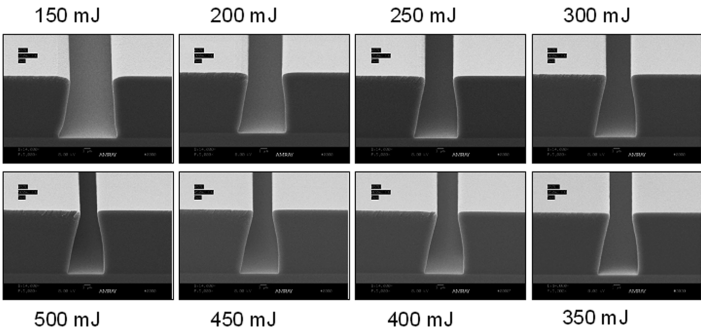


Figure 9 Exposure latitude of 5 μ m isolated trenches on Si wafer; Process conditions: FT=10 μ m; SB: 110 $^{\circ}$ C/120 seconds; Exposed on ASML, f=6.0 μ m; PEB: 115 $^{\circ}$ C/100 seconds contact; DEV: 4x60 seconds spray/puddle.

exposure dose in Figure 10. The difference between the bottom and top opening increased slightly from 2.3 μ m at 250mJ/cm² to 2.7 μ m at 450mJ/cm². The retrograde angle changed from 79 $^{\circ}$ to 77.5 $^{\circ}$ in the same dose range. AZ[®] 15nXT showed good control in opening size without significantly changing the retrograde angle in the broad exposure dose range.

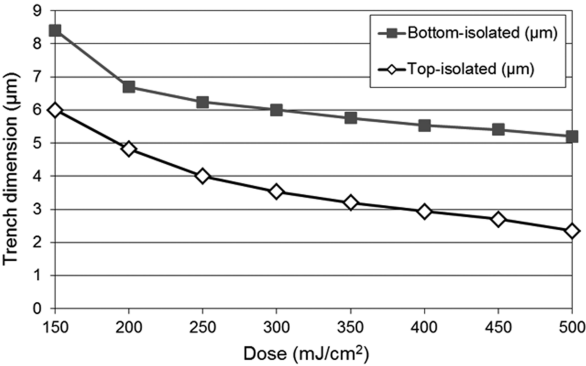


Figure 10 Plot of isolated 5 μ m trench dimension vs exposure dose on Si wafer; Process conditions: FT=10 μ m; SB: 110 $^{\circ}$ C/120 seconds; Exposed on ASML, f=6.0 μ m; PEB: 115 $^{\circ}$ C/100 seconds contact; DEV: 4x60 seconds spray/puddle.

4 Conclusions

AZ[®] 15nXT, a traditional negative tone resist, was shown to have inverted profile capabilities with alternative processing conditions. Lift-off profiles have been achieved on both Suss MA200 broadband aligner and ASML i-line stepper. The DOE was able to give us a nice process window in which to achieve the target lift-off profile. Broad exposure latitude was used to control the size of the opening without significantly changing the retrograde profile angle. The resist was approved to have an inverted profile at both large and small features on the same wafer as well.

5 Acknoledgements

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