Effect of Different Developer Types on Resist Dimension and Side Wall Profile

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Abstract

In this paper, the effects of three different developer base materials on three different resist types and thicknesses were evaluated. The resist profile and dissolution rate characteristics at optimized exposure conditions was studied. Resists (SPR 955-CM 2.1, SPR 220 4.5 and AZ1529) in combination with different developer base materials with and without metal ions (Potassium (KOH), Tetramethylammonium hydroxide (TMAH) and Sodium (Na) were evaluated. Depending on which developer type is used, the resist profile and dissolution rates can vary.

INTRODUCTION

Photoresist can be used for a variety of applications. The most common use is to protect surfaces during etch by which the pattern gets transferred to the underlying material of choice. More often, a thin film of metal, oxides or nitrides is applied as a hard mask. Hard mask improves etch profile and has a higher selectivity compared to resist. These films are typically deposited before the photolithography process. Aluminum (Al), oxides and nitrides are commonly used hard mask for dry etching of deep silicon trenches. AlN and Al_2O_3 are also used as hard masks along with photoresists. However, Al based films are etched/attacked by some popular developer base materials, such as Potassium (KOH) and Tetra methyl ammonium hydroxide (TMAH) [1]. KOH etches both AlN and Al_2O_3 at a rate of 2500+ nm/min and 800+ nm/min respectively [2]. TMAH is less aggressive with etch rates ~25 nm/min [3]. However, with films ranging from 50-100 nm, punch-through or pin-hole generation is a real issue.

In an R&D environment, processes need to be developed quickly for initial evaluation and testing. As a photo engineer, it is important to gather information, such as CD requirements, incoming surface material, chemical or temperature restrictions, etc., to recommend starting process conditions to ensure some success on the initial run. In some cases where, only 1 or 2 wafers are available for initial development work, mistakes can result in wafer loss or scrap, effecting the project. At HRL, we experienced one such issue. A process was developed on a flat Si monitor using a TMAH based developer, a common material used in photolithography. This process was transferred to a test wafer where the resist pattern was over a significant step height. The difference in resist thickness required longer develop times (Fig. 1).

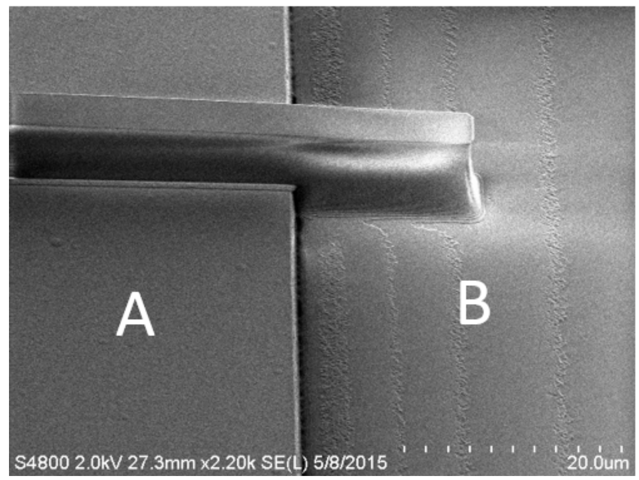

Fig. 1. A = Area exposed to the developer (TMAH) for longer time, resulting it AlN film attack; B = Area requiring longer develop time to clear resist.

There was an alignment issue that required a rework. Unfortunately, the underlying material was an Al based thin film (unknown at the time) and was attacked by the TMAH during the develop step (Fig. 2), removing most of the film, rendering the wafer unusable (or scrapped).

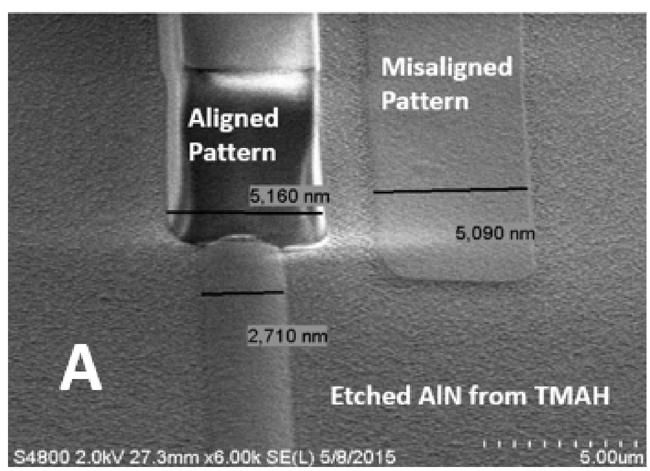

Fig. 2. Wafer reworked due to mis-alignment, the TMAH developer etched the AlN film during the initial photo step.

In these cases, other options are needed to process acceptable features without damaging the underlying thin film material. The use of sodium (Na) based developers is one of those options. Sodium has a very low Al attack rate, and almost non-existent at the proper dilution. However, one cannot just transfer process conditions from one developer type to another without evaluating its effect on resist profile, dissolution rate and feature fidelity. Use of Sodium based developer from the more commonly used TMAH/KOH base developers, required experimental analysis and evaluation of various commonly used resists and developers combination which is presented on this paper.

MATERIALS

Megaposit SPR955 CM is a general purpose, high-throughput, i-line photoresist capable of thicknesses between 0.7 µm and 3 µm [4].

SPR220 is an optimized general-purpose, g-line and i-line resist capable of >10 µm film thickness in a single coat with good uniformity, excellent wet and dry etch adhesion [5].

AZ1529 is a positive tone novolak based photoresist that is sensitive to the entire UV spectrum; g, h, and i line. Used for both wet and dry etch applications with resolution down to 1 µm at 2-4 µm thick. Compatible with all common developers, with the best process latitude using 50-60sec develop time. [6]

Megaposit MF26A is a Metal Ion Free (MIF) (Organic) surfactant containing Developer with 2.38% TMAH that produces high photo speed and improved processing latitude for Conventional and Advanced Photoresists. MIF are recommended where it is desirable to avoid a potential source of metal ion contamination. [7]

AZ 400K Developer is a buffered potassium based developers designed for extended bath life in immersion develop process environments. This developer is recommended for use with most thick DNQ based broadband sensitive photoresists for high contrast and high speed at different normality [8].

AZ Developer is a sodium based developer designed for high selectivity with DNQ type resists and unlike K or TMAH based developers, does not attach Al based films. Material diluted 1:1 with DI for best result [9].

EXPERIMENT

Ultra-flat Si wafers were coated with either 3 µm (SPR955 2.1 and AZ1529) or 6.5 µm (SPR220 4.5) of photo resist. All wafers were exposed on a Karl Suss contact aligner in hard contact mode. SPR955 resist used 365 nm (I-Line) wavelength, SPR220 resist and AZ1529 resist was exposed with broad band wavelength (365 nm/405 nm). Each wafer was developed using a different material (MF26A, AZ 400K and AZ Developer) at various times (10s to 150s). First, a dissolution rate curve was generated for all three types of resist using three different types of developer. Wafers were coated using tracks for better uniformity. The thickness of the resist before and after exposure/develop was measured using a Nanospec. The dissolution rate was calculated for each resist and developer type (Table I). The thickness loss with respect to develop time was also recorded and plotted for SPR955 resist (Fig. 3). To analyze and evaluate the effects of developers on resists (side wall profile and development rate) 6um resolution feature was patterned, developed on a beaker and measured on the CD SEM (Table II) and the profiles were captured using a tilt SEM (Fig. 4, 5, & 6).

RESULTS

Dissolution rate (development rate of photoresist versus time) gives much information about resist, developer and reflection from the substrate. In Table I, dissolution rates of SPR955, SPR220 and AZ1529 were recorded. AZ1529 had the lowest rate compared with the other two developer types, which was expected since it is considered to have a higher development rate compared to other two. SPR 955 and SPR 220 show a similar dissolution rate with all three developers.

TABLE I
DISSOLUTION RATES OF EACH RESIST AND DEVELOPER

Dissolution rates (µm/sec)			
Resist	**MF26A**	**400K**	**AZ 1:1**
SPR955	0.14	0.11	0.1
SPR220	0.13	0.14	0.11
AZ1529	0.07	0.08	0.08

Fig. 3 shows a thickness loss curve of SPR 955 in combination with the 3 different developer types. SPR955 resist showed smooth development rate versus time. As expected MF26A showed the shortest time compared to 400K and AZ developer. AZ developer needs the longest time to completely clear the resist.

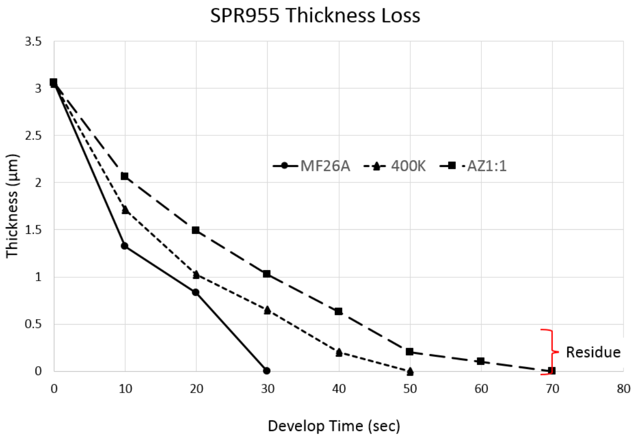

Fig. 3. Thickness loss of SPR955 resist with different developers and develop time.

Table II shows the CD measurement of 2 different develop times for each thickness and developer type. Fig. 4, 5 and 6 show the images of those features for SPR955, SPR220 and AZ1529 respectively. For all resists, the MF26A developer (0.26N) was stronger and resolved the features faster than the other 2 developer types. The MF26A also produced the smallest features for all three resist thicknesses as well. Among the three resists, AZ 1529 showed the highest development rate in combination with MF26A.

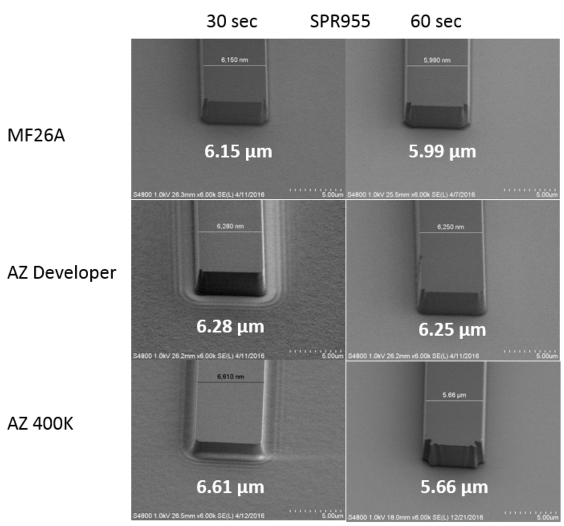

Fig. 4. SPR955 6 µm Resist line in 3 µm of resist.

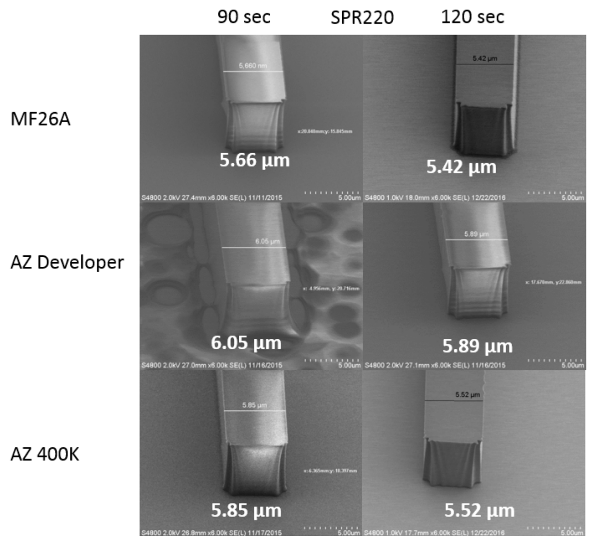

Fig. 5. SPR220 6 µm Resist line in 6 µm of resist.

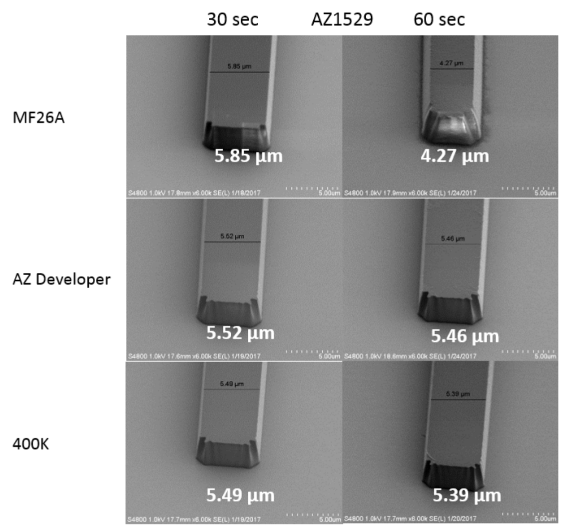

Fig. 6. AZ1529 6 µm Resist line in 3 µm of resist.

The clear times were different for all the resists and developer combination. For the SPR955 resist, the time needed to fully clear the resist using AZ developer (0.30N) was around 60sec and when AZ 400K (0.28N) was used a time of 90sec (not shown) was needed to fully clear the exposed material.

The SPR220 material showed a slightly different result. The AZ400K developer produced similar CD feature sizes and material clear results as the MF26A. Similar to the SPR955 material, it took longer, ~120 sec, to completely clear the exposed resist using the AZ developer. AZ 1529, on the contrary didn't show a significant difference in time varying developers. The optimal time needed to clear the resist was ~30s. AZ developer needed little more time than the MF26A and 400K developer.

MF26A is a more aggressive developer as can be seen by the final feature profiles. The feature patterned with SPR955 resist showed the 2x exposure at the corners of the feature. The SPR220 feature looks to be slightly undercut and the 2x exposure effects at the corner of the feature are also clear. Similar results were observed for AZ 1529. These 2x corner exposure variations were present for all the SPR220 features, but not the SPR955 features using the AZ400K.

TABLE II
CD VS DEVELOP TIME AND MATERIAL: CD MEASUREMENTS FOR THE 3 RESISTS AND 3 DEVELOPERS AT DIFFERENT DEVELOP TIMES (FROM FIG. 4, 5, & 6)

Resist	Developer	Time(s)	CD(μm)	Comments
SPR 955	MF26A	30/60	6.15/5.99	Clear
SPR 955	AZ Developer	30/60	6.28/6.25	Not clear/clear
SPR 955	AZ 400K	30/60	6.61/5.66	Not clear/clear
SPR 220	MF26A	90/120	5.66/5.42	Clear
SPR 220	AZ Developer	90/120	6.05/5.89	Not clear/clear
SPR 220	AZ 400K	90/120	5.85/5.52	Clear
AZ 1529	MF26A	30/60	5.85/4.27	clear
AZ 1529	AZ Developer	30/60	5.52/5.46	clear
AZ 1529	AZ 400K	30/60	5.49/5.39	clear

CONCLUSIONS

Each resist and developer type produced very different results. All developers did resolve the features though additional time was needed for AZ developer and AZ400K. 60s is the optimum time to develop 3 µm of SPR955 2.1 resist using MF26A. However, using a weaker developer in AZ400K will improve the feature fidelity and minimize the corner 2x exposure effects. For the thicker resist, SPR 220 4.5, MF26A has the fastest dissolution rate but severely impact the side wall profile. For the thickness of 6.5 µm, 90s is enough to clear this resist. AZ 1529 shows very high development rate over time. For 3 µm thick resist 30s seems to be enough for all 3 developer types. MF26A showed feature erosion when used over 30s whereas the feature size didn't change drastically with time in case of AZ developer and AZ400K. AZ1529 showed it's compatibility to all 3 types of developer. Therefore, the combination of MF26A and AZ1529 is very aggressive. An alternative to MF26A is AZ 400K which has the similar dissolution rate as MF26A.

For all three resists and 2 different thicknesses the AZ developer requires longer time to dissolve and define feature. This experiment shows that any of the developer types can be used in the photo process with SPR955, SPR220 and AZ1529. Based on the initial problem (TMAH attack on AlN), it is clear that the AZ developer would be a suitable material of choice if the underlying film was Al based.

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ACRONYMS

TMAH - Tetramethylammonium hydroxide
KOH – Potassium Hydroxide
NaOH – Sodium Hydroxide
CD – Critical Dimension
AlN – Aluminum Nitride
Al_2O_3 – Aluminum Oxide
SEM – Scanning Electronic Microscope