Advanced wafer drying technology for 1x node and beyond using surface modification method

T.Watanabe*, T, Orii*, T. Toshima*, M.Nakamori**, K.Egashira*, Y.Ido*
*Technology Development Center, Tokyo Electron Kyushu Limited. 650 Mitsuzawa, Hosaka-cho, Nirasaki-city Yamanashi-Prefecture, Japan
** SPE Process Technology Department Tokyo Electron Kyushu Limited, 1-1 Fukukara, Koshi-city, Kumamoto-Prefecture, Japan

Introduction

As pattern dimensions of semiconductor devices shrink, patterns with high aspect ratio (HAR) stick together during dying. The phenomenon is called ‘Pattern collapse’ and it is currently the most important challenge in surface preparation processes for fabricating memory devices of 1x node and beyond. The Laplace force generated by liquid between structures is the main cause of pattern collapse [1]. A simplified model is presented in Fig.1. The force *F* is proportional to the surface tension of liquid times the cosine of contact angle and inversely proportional to the distance between the structures. IPA dry has been used as a method to prevent pattern collapse instead of spin dry since it is easy to install for single wafer tools. However, it is reaching the limit of process margin since IPA surface tension is only one third that of water.

We focused on the other parameter which decides Laplace force: contact angle. When the contact angle is close to 90deg, the force approaches zero, which enables larger process margin for next generation structures. We call this concept of drying ‘Hydrophobized Surface Dry’. (HSD)

Potential comparison by simulation

We compared the potential of IPA dry, F-based solvent (with very low surface tension) and HSD by calculating the threshold aspect ratio (AR) of generating pattern collapse. The calculation is based on the formula presented by Chin, et.al. [2] including not only Laplace pressure, but also the deflection of the structure and surface tension force. We considered the simplest case with only two structures with a wetted space between them.

[Calculation condition]

- Pattern size and feature : Vertical line and space pattern with 18nm width (1: 1 pitch, 2 dimensions)
- Material : Si (Young’s modulus : 112[GPa])
- Parameters of liquid between structures : Refer to below

	IPA dry	F-solvent dry	HSD
Liquid	IPA	F-Solvent	Water
*Surface tension[mN/m]	22	14	73
Contact angle[deg]	10	10	92

* Value @20degC

Fig.2 is the result of the simulation showing critical AR for various techniques. Results indicate that critical AR for HSD is 1.7 times higher than for IPA dry.

Experimental

We selected a chemical to make the surface of structures hydrophobic, depending on structure materials. Silylation agents are effective for treating the surface of Si-based materials such as thermal oxide and silicon substrates.

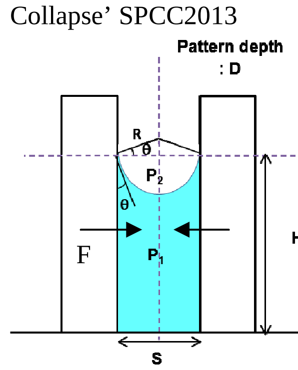
We fabricated HAR L&S structures to evaluate the effectiveness of HSD. Dimensions are equivalent to 1x node memory with aspect ratio around 19. We compared the performance of HSD to IPA dry by observing the cross-section surface after cleaning and drying. We used the silylation agent TMSDMA (Trimethylsilyldimethylamine) diluted by a solvent and we confirmed that the contact angle between blanket SiO2 wafer and water reached around 90deg. Fig.3 is the cross-sectional SEM picture after drying. 3 lines stick together after IPA dry and no collapse was found after HSD.

Summary

We proposed a novel concept of ‘Hydrophobized Surface Dry’ (HSD) and proved its effectiveness from calculation and experiment using 1x node pattern sample.

References

[1] Tanaka, T.; Morigami, M.; Atoda, N. ‘Mechanism of resist pattern collapse during development process’. *Jpn. J. Appl. Phys.* 1993, *32*, 6059–6064.
[2] S. Farshid Chini and A. Amirfazli ‘Understanding Pattern Collapse in Photolithography Process Due to Capillary Forces’ * Langmuir 2010, 26(16), 13707–13714
[3] Derek Bassett, Mike Carcasi, Wallace Printz ‘Finite Element Modeling for Prediction of Line Pattern Collapse’ SPCC2013



Pressure difference
$\Delta P = P1 - P2 = -\gamma/R = 2\gamma\cos\theta/S$
$F = (2\gamma\cos\theta/S)*H*D$
$(R = S/2*\cos\theta)$
(γ : Surface tension, R : Curvature radius)

Fig.1 Simplified model of the force generating pattern collapse

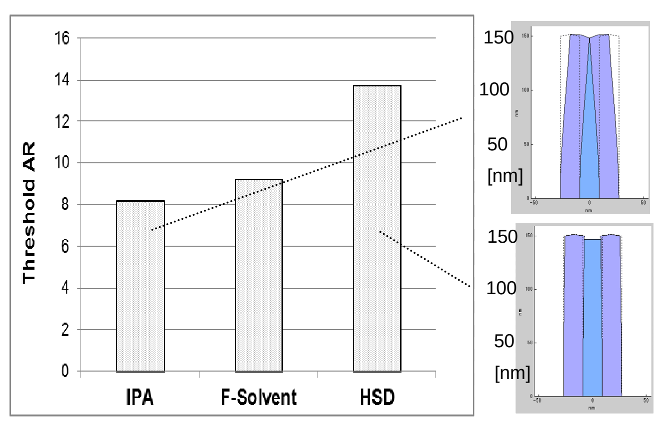
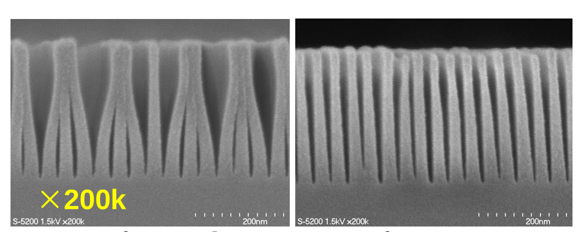


Fig2.Comparison of potential of IPA dry and HSD



After IPAdry Afer HSD

Fig3 Cross-sectional CD-SEM view of IPA dry and HSD