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# Global Planarization with Viscosity Control for an Advanced STP Process

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## 1. Introduction

STP (Spin coating film Transfer and hot-Pressing) is a film depositing and planarization technology based on a new concept [1]. The concept is to spin-coat a base film with a dielectric and to transfer it from a base film to a wafer by hot-pressing in a vacuum as shown in Fig. 1. Unlike CMP (Chemical Mechanical Polishing), this process does not require mechanical strength for planarized material, and it is expected to be suitable for novel applications like the pillar process [2]. To examine and brush up STP, we developed an advanced film transfer system and improved fundamental transfer properties [3]. Previous investigations also showed that this principle could truly realize planarization and gap filling of sub-micron interconnects with thin films of inorganic SOG [1]. However, the material applicable to STP was limited to only inorganic SOG. Furthermore, it was not clear to what extent large patterns could be planarized. In this paper, we propose how to control the material properties to make materials applicable to STP and show the experimental results for planarized large-scale patterns with thick films of organic low-k dielectric, which are in good agreement with the theoretical analysis. The results also show that STP can planarize patterns as large as 500 $\mu$m.

## 2. Effect of Viscosity on Gap Filling and Planarization

Figure 2 shows the results of planarization and gap filling without optimization using photosensitive low-k (k=2.9) organic dielectric. In Fig. 2(a), the line-and-space pattern (L&S) is 2-$\mu$m wide, and the gaps were not filled at all, though the surface was planarized by the base film. In Fig. 2(b), gap filling stops halfway. This is because larger patterns need a larger dielectric flow to be filled; the viscosity of the dielectric was too high to flow by pressing in a vacuum.

In general, there are several ways to control viscosity of fluid materials with solute and solvent: reforming the chemical properties of the solute itself, adding additives to the fluid, or changing the proportion of the solvent to the solute. Considering that the STP process always includes the vacuum process in Fig. 1(b) and a more applicable way independent of other material properties is preferable, it is convenient and simplest to control viscosity by vaporizing an appropriate amount of solvent when evacuating the chamber.

The relationship between the chamber pressure and the viscosity was measured at 100℃ in Fig. 3. The viscosity becomes higher as the chamber pressure becomes lower, because the solvent vaporizes more quickly at a lower chamber pressure. This means viscosity is generally controllable with chamber pressure.

To analyze the effect of viscosity on gap filling, we investigated the mechanism with a simple model in case of the L&Ss in Fig. 4. From the symmetry, it is sufficient to consider that gap filling finishes when the external pressure pushes out the dielectric fluid within $0 \leqq x \leqq A$ to fill the gap completely within $A \leqq x \leqq B$ as shown in Figs. 4(a) to (c). When $q(t, \eta)$ is defined as the total amount of flow crossing x=A at a time t with viscosity $\eta$, the relationship between $q(t, \eta)$ and $\eta$ is given as shown in Fig. 5 from an approximate expansion of the analytical solution of Navier-Stokes equation for two-dimensional Poiseuille flow within $0 \leqq x \leqq A$ and the preservation law within $0 \leqq x \leqq B$ [see Appendix].

From Fig. 3 and Fig. 5, the chamber pressure 2 kPa, corresponding to the viscosity 420 Pa·s, is enough to fill the gap completely. On the other hand, when the chamber pressure is 65 Pa, the viscosity is so high that gap filling is incomplete. In this way, we can predict the required relationships for complete filling between pattern sizes, viscosity, and process conditions.

## 3. Characteristics of Gap Filling and Planarization

To investigate the characteristics of gap filling and planarization, the dielectric was transferred to a Si wafer with patterns. The chamber pressure was 2 kPa. We obtained the planarized lines and filled gaps of small L&Ss 0.5-$\mu$m wide to large L&Ss 100-$\mu$m wide. A 500-$\mu$m square pattern was also planarized. Though large patterns are difficult to planarize owing to a large flow, the much wider L&S (100-$\mu$m wide) in Fig. 6 (concerned to that in Fig. 2) was completely filled and globally planarized.

The surface profiles were measured on line patterns 100-$\mu$m wide planarized by STP in Fig. 6 and compared with that by conventional spin-coating. From Fig. 7, the variation of the surface profile by STP was $\pm$0.43%, while that by spin-coating was $\pm$1.66%. Therefore, STP planarizes large L&Ss even 100-$\mu$m wide and a 500-$\mu$m square pattern independent of pattern sizes.

## 4. Summary

We have shown that it is effective to control the viscosity of photosensitive organic low-k dielectric by vacuum drying and achieved global planarization of large patterns. An analytical model also described well the relationship between viscosity and gap filling. These experimental and theoretical investigations showed the viscosity conditions and pattern sizes for global planarization and established a way to make many kinds of material applicable to STP.

**Acknowledgments**

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**References**

[1] K. Machida *et al.*, J. Vac. Sci. Technol. B **16**, 1093 (1998).
[2] A. Kajita *et al.*, *Proc. IITC*, (1999) p. 259.
[3] N. Sato *et al.*, *Proc. ADMETA2000*, (2000) p. 31.

**Appendix**

The explicit expression of the analytical solution is

$$q(t,\eta)=\begin{cases}\left(H-C-\sqrt{\dfrac{6\eta A^2(H-C)^2}{6\eta A^2+P(H-C)^2 t}}\right)\cdot A & (0\le t\le\tau)\\ \dfrac{(B-A)A}{B}\cdot C & (t>\tau)\end{cases}$$

$$\tau=\frac{6\eta A^2}{P(H-C)^2}\cdot\frac{C(B-A)\{2HB-C(3B-A)\}}{\{HB-C(2B-A)\}^2},$$

where H is an initial height of the dielectric surface, C a depth of the gap and P an external pressure. The normalized flow was defined as q(t, $\eta$ )/{(B-A) · (A/B)}.

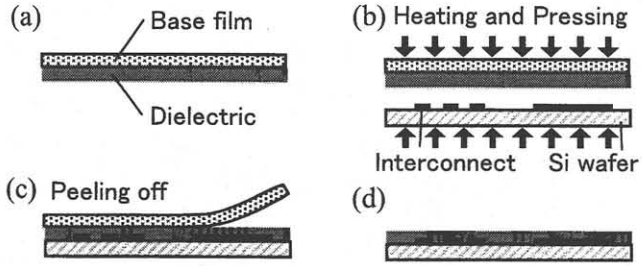


Fig. 1 STP process flow. (a)Dielectric is spin-coated on a base film. (b)Dielectric is heated and pressed against a wafer in a vacuum. (c)Base film is peeled off. (d)Dielectric was planarized.

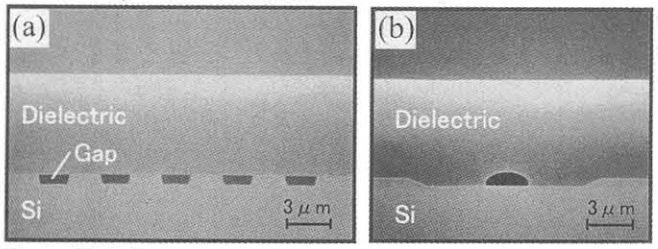


Fig. 2 SEM photographs of incomplete filling.

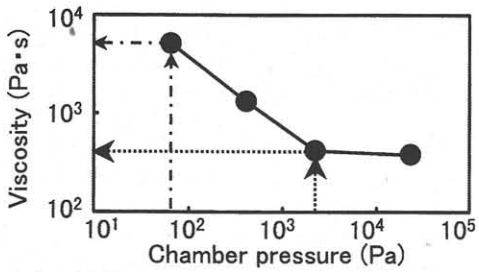


Fig. 3 Relationship between viscosity and chamber pressure measured at 100℃.

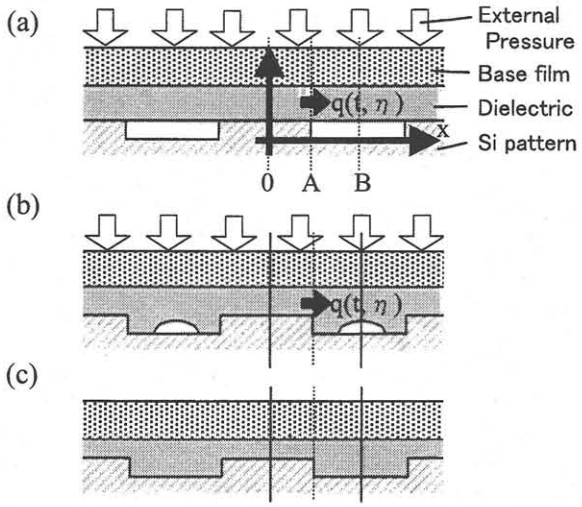


Fig. 4 Analytical model of dielectric flow (a) before, (b) during and (c) after pressing.

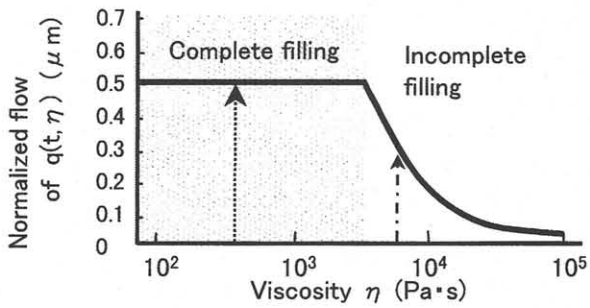


Fig. 5 Simulated relationship between normalized flow and viscosity at t=30sec. The total amount of flow q(t, $\eta$ ) was normalized in order to correspond to the depth of the gap. A L&S 100-$\mu$m wide and 0.5-$\mu$m deep, an external pressure of 3.5 kPa and a spin-coated dielectric 7.0-$\mu$m thick were assumed.

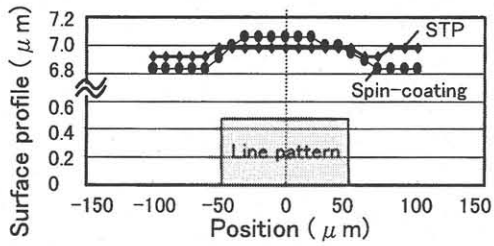


Fig. 7 Surface profiles of dielectrics on the 100-$\mu$m wide line pattern by STP and spin-coating.

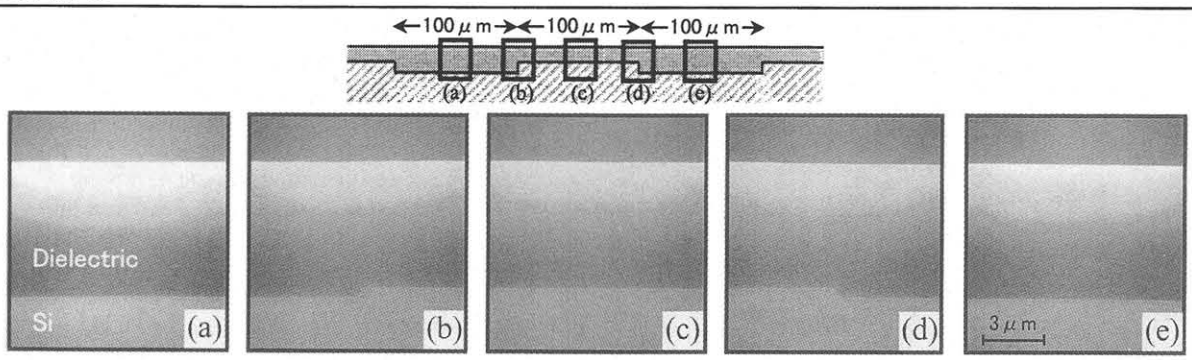


Fig. 6 SEM photographs after STP at a L&S 100-$\mu$m wide.