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Glass Flow Mechanism of Phosphosilicate Glass and its Application to MOS Devices

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When phosphosilicate glass is annealed at high temperatures, the glass surface will tend to change its shape so as to reduce the surface energy to a minimum. This "Glass Flow" effect can be used to control the step profile of the PSG film in MOS devices.

This report concerns a quantitative study of "Glass Flow" effects. The flattening mechanism and the effects of phosphorus concentration, annealing temperature and ambient on the step profile change were clarified. Optimization of the glass flow conditions can be carried out using attenuation rate constant L.

The mass transport processes to reduce the surface energy are classified into viscous flow, volume diffusion, surface diffusion and evaporation-condensation. We used the muitiple-scratch smoothing method to analyze the surface flattening of the PSG films. A typical step profile of the PSG film as shown in Fig. 1 can be expressed as follows,

$$Z(x,0) = \sum_{n=1}^{\infty} A_n . \sin(n\omega x),$$

where $\omega(2\pi/\lambda)$ is the angular frequency of the steps and λ is the wave length, namely, the center to center spacing of the steps. When the steps are annealed at high temperatures, this profile changes according to next equation,

$$Z(x,t) = \sum_{n=1}^{\infty} A_n . \sin(n\omega x) \cdot \exp(-L_n \cdot t),$$

where t is the annealing time and $L_n = F(n\omega) + A(n\omega)^2 + C(n\omega)^3 + B(n\omega)^4$. Attenuation rate constant L_n is obtained from the combination of the four transport processes. The first term denotes viscous flow, the second, evaporation-condensation, the third, volume diffusion and the fourth, surface diffusion. After annealing the profile can be expressed into a sine wave, that is

$$Z(x,t) = A_1 . \sin(\omega x) . \exp(-L_1 . t).$$

The decay $Z(x,t)/Z(x,t_0)$ of the step was measured using a multiple beam interferometer. The mechanism is determined by the dependence of the decay on angular frequency ω .

The dependence of the ratio of amplitude A at an annealing time t to the initial amplitude A_0 upon the angular frequency $\omega(2\pi/\lambda)$ is shown in Fig. 2. The relationship between ln (A/A_0) and the fourth power of angular frequency ω is linear. From this result, surface diffusion is dominant in the flattening process of the PSG step which contains 6mol % P_2O_5. As the attenuation rate constant L is equal to $B\omega^4$, B can be calculated at about 0.45 μm^4/ hr. Such a relationship was

determined under various conditions of annealing temperature and P_2O_5 concentration. The results are summarized in Table 1. The "Glass Flow" mechanism is characterized as follows; viscous flow is dominant at high P_2O_5 concentrations and surface diffusion is dominant at low P_2O_5 concentrations.

The step profile changes of the PSG films corresponding to the attenuation rate constant L are shown in Fig. 3, to make clear the relationship between L and the actual profile used in the polycrystalline Si-gate MOS LSI. Thus, the annealing conditions for controlling the PSG profile which is compatible with device processing can be chosen using the attenuation rate constant L .

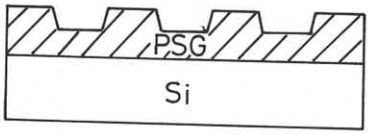


Fig. 1 A step profile of PSG film

Table 1 The dependence of the decay on angular frequency and values of attenuation rate constant (λ = 10 μm)

P_2O_5 Concentration \ Annealing Temp.	900°C	950	1000	1050	1100	1150
14 mol %	w^2~w^3 L=0.15	w^3 1	w^2 3			
6			w^4 0.03	w^4 0.03	w^4 0.07	w^4 1.3

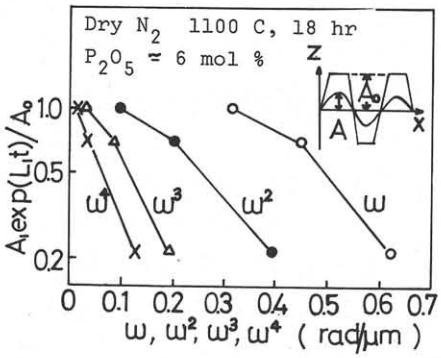
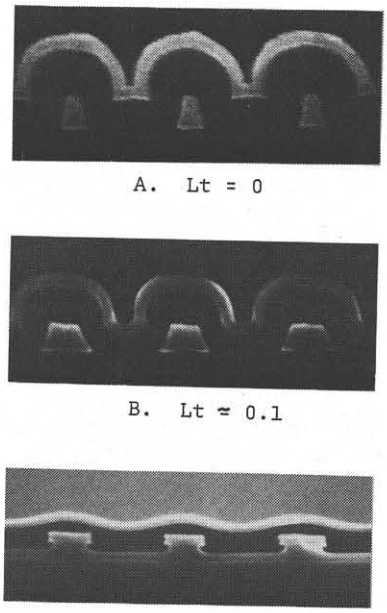


Fig. 2 The dependence of the decay on angular frequency



A. Lt = 0

B. Lt ≃ 0.1

C. Lt ≃ 1

Fig. 3 Step profile change of PSG films