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Function of Phase Switch Layer for Ultra Shallow Junction Formation by Green Laser Annealing

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1. Introduction

The scaling of MOSFET has been requiring the process to form ultra shallow junction to avoid the short channel effect. Excimer laser anneal has been investigated as a one of solution of the request [1]. Recently, all-solid-state green laser anneal process was investigated because of the laser stability and the cost in comparison with excimer laser annealing. Light absorber was utilized to compensate the too small absorption coefficient of Si at the wavelength of 532 nm. A TiN layer as the light absorber lowered the required laser power density to activate the dopants by 0.3 J/cm2[2-4]. However, process window became very narrow. Phase switch layer to cut the light energy above its melting point because of reflectance difference between solid phase and liquid phase was investigated to enlarge the process window [5]. The function of the phase switch was explained only by qualitative model. In this paper, the roles for the phase switch layer and the light absorber for laser anneal process was discussed based on numerical analysis of one-dimensional thermal diffusion equation considering light interference effects.

2. Simulation model

One-dimensional thermal diffusion was analyzed considering heat generation by laser absorption in the similar manner to our previous works [2,3]. Characteristic matrix method [6] was employed to consider the effect of multiple thin film interference. The magnitude of electric field and magnetic field at both side of thin film are connected with the matrix. Light interference was also treated to obtain exact light intensity in a multi-layered structure. The phase transition among a-Si, liq-Si and c-Si was treated by enthalpy based method. Other phase transition was ignored because the melting points are high enough.

A typical structure of the one-dimensional thermal diffusion model is shown in Fig. 1. The Si surface was assumed to be a-Si for 20 nm by the pre-amorphization implantation. A SiO_2 layer was inserted between a Si substrate and the light absorber to avoid the silicidation reaction. Poly-Si or a-Si were assumed as phase switch materials. The thickness of phase switch layer was varied from 10 nm to 40 nm that gives minimum and maximum reflectance as shown in Fig. 2, respectively.

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3. Results and Discussion

Figure 3 shows the melt depth of the pre-amorphized layer as a function of laser energy density for three kind of structures. The plateau regions are seen for all structures. The regions are energy ranges where only pre-amorphized layer melts because of the melting point difference between a-Si and c-Si. The energy range of the plateau region was defined as a process window width. According to Fig. 3, although TiN light absorber reduced energy range necessary for melting process, it narrowed the process window compared to no absorber case. On the other hand, the a-Si phase switch with TiN absorber improved both the minimum energy density for melting and process window width. Figure 4 summarizes the energy ranges of the process windows for various film structures.

Figures 5 shows temporal laser power density at surface of the phase switch layer and the Si surface. Incident laser intensity, melt depths for the phase switch layer and pre-amorphized Si layer are also plotted in these figures. The difference between incident laser intensity and intensity at the phase switch surface reflects the energy loss due to surface reflection. Large reduction in the intensity at the phase switch surface is attributed to increase in reflectance by melting. Low intensity at the Si surface indicates most part of laser energy was absorbed in the upper additional layers and substrate is mainly heated by thermal diffusion. Since the a-Si phase switch melts before the pre-amorphized layer melts, reflectance transient for the a-Si phase switch shown in Fig. 5 is more complex than that for the poly-Si phase switch in Fig. 6. Regardless of phase switch materials, the negative feed-back effect by phase switch melting that reduces effective intensity and suppresses over-melting of the substrate was numerically confirmed. Figures 7 shows transient laser power density at the Si surface for various irradiation energy densities. As the irradiation energy becomes higher, the intensities at the Si surface becomes lower. This effect is caused by the increase in surface temperature and resultant reflectance increase. This is also effective to suppress the over-melting and to enlarge the process window width.

3. Conclusions

Time evolution of light intensity and temperature was numerically simulated to discuss how the phase switch behaves during laser irradiation for laser annealing. Thickness of the phase switch should be set to antireflection condition. In addition to fundamental function of the phase switch obtained by melting, heat-up of melted phase switch provides further advantage for over-melt suppression.

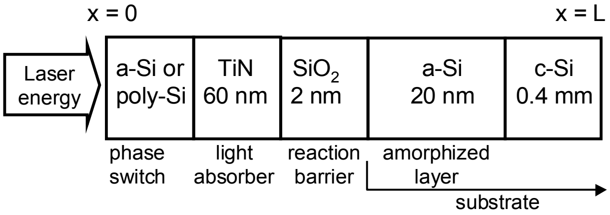

Fig. 1 The structure of the one-dimensional simulation model

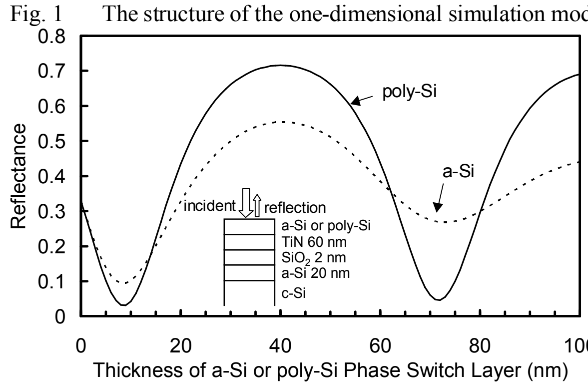

Fig. 2 Relationship between reflectance and a-Si or poly-Si phase switch layer thickness

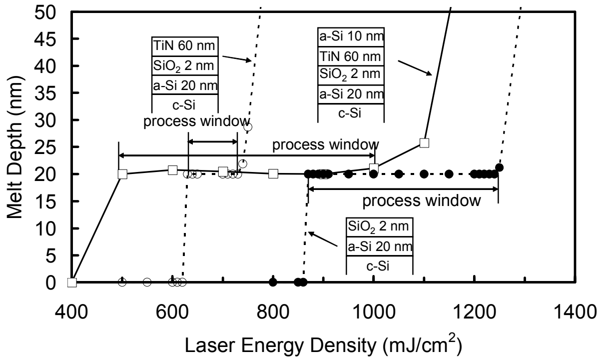

Fig. 3 The effects of a-Si phase switch layer and TiN light absorber on the melt depth of pre-amorphized layer as a function of laser energy density

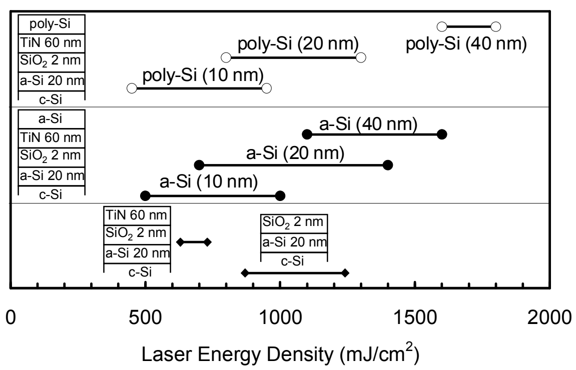

Fig. 4 Process windows of laser energy density evaluated from relationship between melt depth and laser energy density

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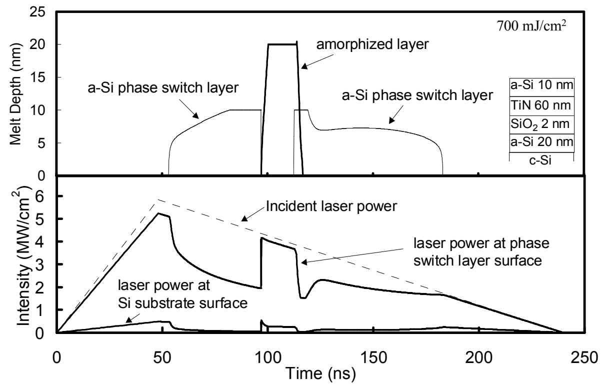

Fig. 5 Temporal melt depth of surface a-Si phase switch layer and surface of Si substrate with incident laser intensity, laser intensity for surface of a-Si phase switch layer and surface of Si substrate

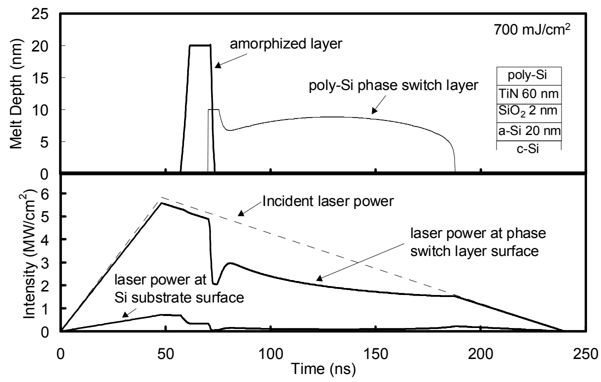

Fig. 6 Temporal melt depth of surface poly-Si phase switch layer and surface of Si substrate with incident laser intensity, laser intensity for surface of poly-Si phase switch layer and surface of Si substrate

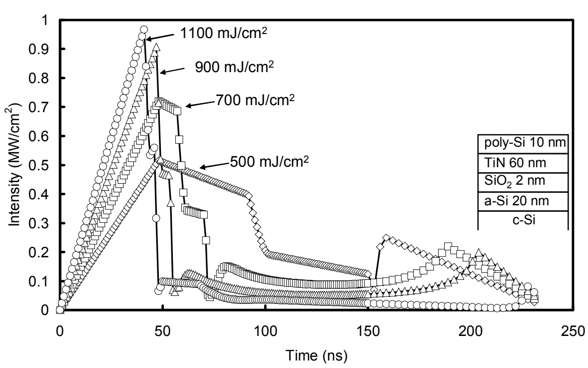

Fig. 7 Temporal laser intensity at the surface of Si substrate in case of poly-Si phase switch layer