STUDY ON DAMAGES IN ION-IMPLANTED Si USING TRANSIENT REFLECTING GRATINGS

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Abstract - The transient reflecting grating method has been used to characterize ion-implanted silicon layers. The signal intensity and relaxation constant were measured as functions of ion dose. The results suggested that damage induced by ion-implantation suppresses thermal diffusion even under a light dose condition.

Key words: transient grating, ion-implantation, silicon

Surface modification techniques such as ion-implantation are of increasing technological and scientific interest. For instance, ion-implanted silicon is not only used for electronic devices but also as a structural material for micromachines. As precise ways of surface modification are being developed, it becomes important to study the modified surfaces remotely and nondestructively. Recently, we proposed a novel microscopic method [1] utilizing the transient reflecting gratings. [2] It was demonstrated that this method was very sensitive to ion-implantation induced changes in the surface properties. However, a clear explanation of the results could not be given at that stage, since there are complicated processes in the transient grating formation. The purpose of the present research is to identify the dominant factors in transient reflecting grating experiments on ion-implanted silicon surfaces.

EXPERIMENTAL

The experimental setup is shown in Fig.1. The laser system consists of a mode-locked Q-switch Nd:YAG laser, a single pulse selection unit and a frequency doubler. 80 ps pulses at a wavelength of 532 nm are produced with a repetition rate of 1 kHz. A single light pulse is divided into three parts. Two of them are overlapped spatially and temporally at the sample surface with a crossing angle of $2\theta_c$. They excite the transient reflecting gratings. As a result of optical absorption and successive nonradiative relaxation, a temperature profile is formed on the surface (i.e. thermal grating). It spatially mimics the optical interference pattern having a grating period $\Lambda = \lambda_c / 2 \sin \theta_c$, where λ_c is the wavelength of the light. Additionally, thermal expansion induces a strain and generates

Fig.1 Experimental setup of the transient reflecting gratings. (AP):aperture, (HM):half mirror, (ND):neutral density filter, (PD):photodiode, (PRM): partial reflective mirror, The other optical elements are prisms and mirrors.

counterpropagating coherent surface acoustic waves (SAW). The photoexcited carrier gratings may also be generated, but under the present experimental conditions, temperature rise is considered to dominate the grating formation on the silicon surface. The beams have a diameter of 60 μm and are each attenuated to less than 1 μJ per pulse. Both the SAW and the thermal grating can be observed using diffraction of a third laser pulse (a probe pulse) incident at the excited region. The diffracted light is detected with a photodiode and its intensity is averaged with a boxcar integrator. The samples measured were silicon wafers undergoing 300 keV argon ion implantation at a room temperature. Measurements were carried out for samples having various ion doses (10^{11} to 10^{17} atoms/ cm^2) on (001) surfaces.

Fig.2 Typical response of the transient reflecting gratings on the argon-implanted silicon taken at 1.54 μm grating period.

RESULTS AND DISCUSSION

Figure 2 shows a typical transient response of the signal taken at 1.54 μm grating period. The damping oscillations due to SAW are superimposed on the decay component due to energy diffusion parallel to the surface. The transient response curve $S(t)$ is approximately expressed by [2]

$$S(t) \propto \{F \cos(2\pi f_a t) \exp(-t/\tau_a) - \exp(-t/\tau_t)\}^2$$

where f_a is the SAW frequency, τ_a is the attenuation constant of the SAW, τ_t is the relaxation constant of the thermal grating, and F is the contribution ratio to diffraction between the acoustic and thermal

components. The relaxation constant τ_t is given by $\Lambda^2/4\pi^2 D$, where D is the thermal diffusivity of the sample. For each sample having various ion doses, both relaxation constant and maximum signal intensity were determined from the measured transient response curves. Figure 3 shows two correlations between these parameters and the ion dose. The result shows that the signal intensity increases as the ion dose increases and that the relaxation constant increases at the same time. A qualitative interpretation of the general features of Fig.3 is as follows: a higher signal intensity may correspond to a greater local lattice temperature, indicating a higher rate of nonradiative recombination at the surface of the ion-implanted region and a lower rate of lateral thermal diffusion. This is consistent with an increase in defects and dislocations at the near surface. A decrease in thermal diffusivity by ion-implantation has been

observed at the implantation dose of 10^{13} atoms/ cm^2 by photothermal measurements. [3] Here the same feature is seen under even lighter dose conditions [10^{11} atoms/ cm^2]. It should be noted that the implanted depth of argon ions is comparable to the region in which material properties dominate the signal response. The optical penetration depth to crystalline silicon is about 400 nm at the light wavelength of 532 nm, and the thermal diffusion depth $(Dt)^{1/2}$ is 600 nm, where D is the thermal diffusivity of crystalline silicon ($D = 0.9 \text{ cm}^2/\text{s}$) and t is the maximum delay time of the observation ($t = 4 \text{ ns}$). These values promise that this method can be successfully used to observe ion-implanted regions.

Fig.3 Argon-ion dose dependence of the relaxation constant (O) and the maximum signal intensity (●).

REFERENCES

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