Single-shot reflectivity study of the picosecond melting of silicon using a streak camera

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1. Introduction

Numerous investigations on the phase transition of silicon during picosecond laser annealing have been performed in recent years. It has been well established that the silicon surface melts during a picosecond laser pulse.[2] Because liquid silicon is a metal, the reflectivity increases on melting. This has indeed been observed using optical pump-and-probe techniques.[2-4] Standard picosecond pump-and-probe measurements, however, have some serious inherent drawbacks. First, they cannot resolve reflectivity changes that occur on a time scale of a few picoseconds, because they integrate over the duration of the probe pulse (typically 20 ps or more). Second, they determine the time profile of the reflectivity for every pump fluence in a step-wise manner by varying the delay between the pump and the probe pulse. This introduces a large amount of scatter in the data points, due to shot-to-shot variations in the pump fluence, and requires a large amount of data to be taken for every time profile of the reflectivity. Also, they provide no spatial information on the melting process.

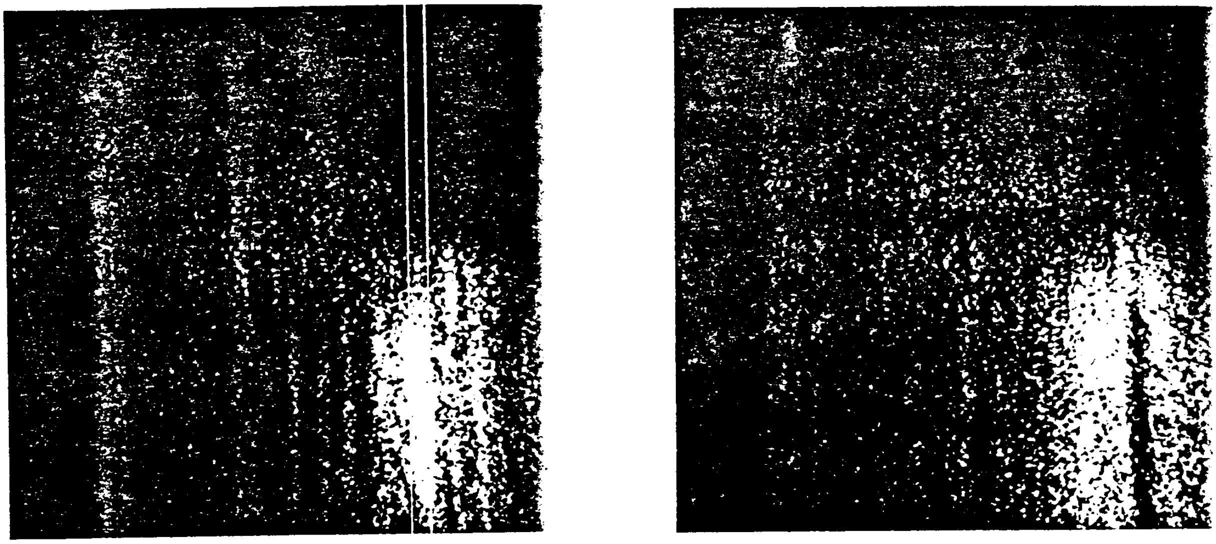
To obtain spatial resolution, a better time resolution, and to measure the time profile of the reflectivity on a single-shot basis, we use a streak camera with a time resolution of 1.8 ps for the detection of the probe pulse.

2. Experimental setup

The frequency-doubled output (30 ps, 532 nm) of a mode-locked Nd:YAG laser is split into a probe and a pump pulse. The duration of the probe pulse is stretched by splitting it in four, delaying the four resulting pulses with respect to each other, and recombining them spatially to form a longer probe pulse of 120 ps duration. The probe pulse then images an area around the 100-μm wide melting area onto the entrance slit of a streak camera (Hamamatsu Photonics C1587).

The entrance slit of the camera is split into two parts. The larger part is used to image the probe pulse, the smaller part to image a fraction of the pump pulse. The latter acts as the timing reference.

To enhance the sensitivity of our measurements, the probe pulse is *p*-polarized and the probe angle of incidence is chosen to be 65°, close to Brewster's angle. At this angle the



(a)

(b)

Fig. 1. Streak camera images of laser melting of silicon. Laser fluence is 470 mJ/cm^2. The white lines in (a) indicate the region used for analysis of the reflectivity.

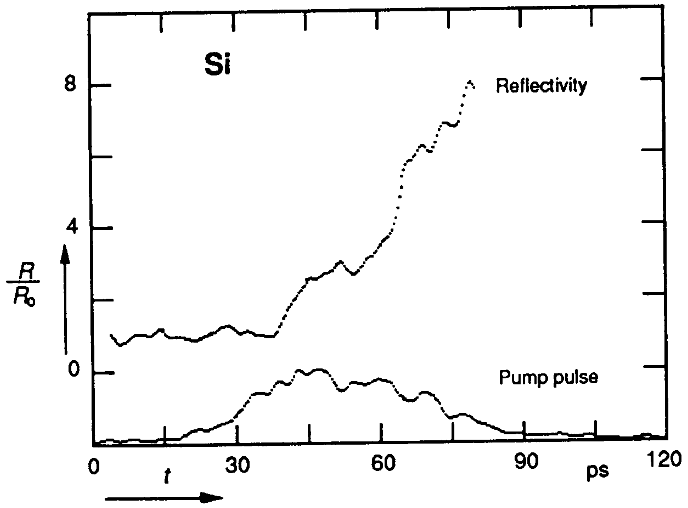


Fig. 2. Reflectivity of silicon during melting with a picosecond laser pulse. R_0 is the reflectivity of solid silicon. The lower trace shows the intensity of the pump pulse.

reflectivity of solid silicon is small (about 10%), leading to an increase in reflectivity on melting of a factor of 8.

3. Results and Discussion

The streak images of two measurements are shown in Figs. 1a and 1b. The time axis is displayed vertically, with time increasing from top to bottom. The full height of the image corresponds to 190 ps. The horizontal axis reflects the spatial profile. The pulse shown on the left side, with a width of about 30 ps, is the pump pulse. The stretched probe pulse covers most of the image. The bright part is where the silicon surface is melting. Spatially it reflects the Gaussian intensity profile of the pump pulse. The time profile allows one to study the melting dynamics.

Both measurements were performed at the same laser fluence. In the case shown in Fig. 1b, some surface irregularity leads to the formation of a plasma on the surface in the region where the absorbed energy is highest. The plasma scatters the incoming probe light, leading to the dark area in the center of the melting region. This clearly emphasizes the need for spatial resolution. An integrating detector would give rise to erroneous conclusions about the reflectivity.[5]

Fig. 2 shows the reflectivity profile at the center of the melting region, between the two white lines, in Fig. 1a. The reflectivity reaches the value for liquid silicon within the 30-ps duration of the pump pulse. The high time resolution of the streak camera enables us to confirm, that the reflectivity follows the trend predicted by numerical simulations of heating above the melting temperature in silicon.[3] According to a Drude model one expects a decrease in reflectivity of molten silicon when it is heated above the melting temperature. The laser fluence in Figs. 1a and 1b is 470 mJ/cm^2 which is more than twice as large as the melting threshold for silicon (200 mJ/cm^2). A numerical solution of the one-dimensional heat equation shows that at this fluence the temperature of the liquid silicon exceeds the melting temperature by more than 1000 K.

Measurements with longer and more uniform probe pulses are currently in progress.

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