Backside Surface Machining of Silicon Wafers Using a Nanosecond Tm:fiber MOPA System

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Abstract: We report on selective machining of the back surface machining of double-side polished silicon wafers, using a high peak power nanosecond Tm:fiber master oscillator power amplifier with a photonic crystal fiber based power amplifier.

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Introduction

Pulsed thulium fiber lasers have been primarily developed for applications such as LIDAR and pumping optical parametric oscillators; however, these systems also offer unique capabilities for processing semiconductors, which are transparent in the 2 μm wavelength regime. As part of other investigations of materials processing using nanosecond Tm:fiber lasers [1,2], in this work we describe selective machining of the back surface of 500-μm thick double-side polished silicon wafers without causing damage to the front surface. We present our initial investigations of damage threshold and the process dependence on laser parameters such as pulse duration and incident fluence.

Experimental Setup

The Tm:fiber master oscillator power amplifier (MOPA) system used in these experiments is described in [3]. Critically it produces polarized output with 290 μJ energy, 6.5 ns duration, <1 nm spectral width, and quasi diffraction-limited beam quality due in large part to the unique properties of the Tm-doped photonic crystal fiber (PCF) [4] used in the power amplifier. The output beam is focused at normal incidence from above onto 500-μm thick silicon wafers using a 7.5 mm focal length aspheric objective producing a sub-15 μm spot size on focus. Given a 67% transmission efficiency from the Tm:fiber MOPA output to the front surface of the silicon wafer, the maximum fluence on target is ~250 J/cm^2. As shown in Fig. 1, the sample is placed on a 3D motorized motion control stage and a mechanical shutter to facilitate controlled hole drilling and trench cutting experiments.

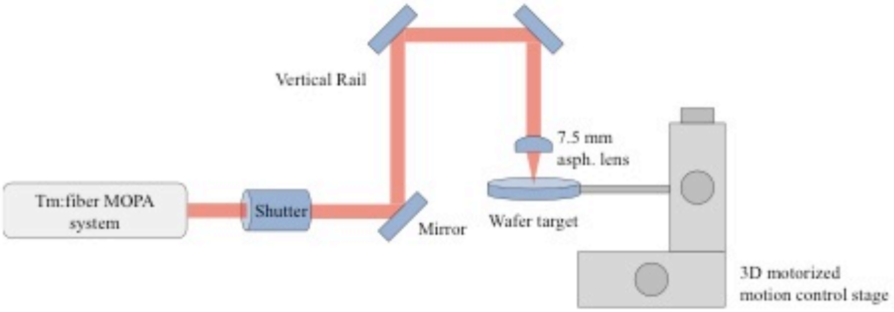

Figure 1: Schematic of the experimental setup for machining

Results

By measuring the crater diameters formed by 1000 pulses as function of incident laser fluence as described in [5] we calculate the front surface damage threshold to be ~2.4 J/cm^2 with a 14 μm diameter minimum focal spot. This threshold value is similar to the 4.8 J/cm^2 measured for the same pulse duration at 1 μm wavelength by Wang et al. [6]. As shown in Fig. 2, optical microscope images of ablation features on the upper surface show clear signs of melting and vaporization as expected for ablation with nanosecond laser pulses.

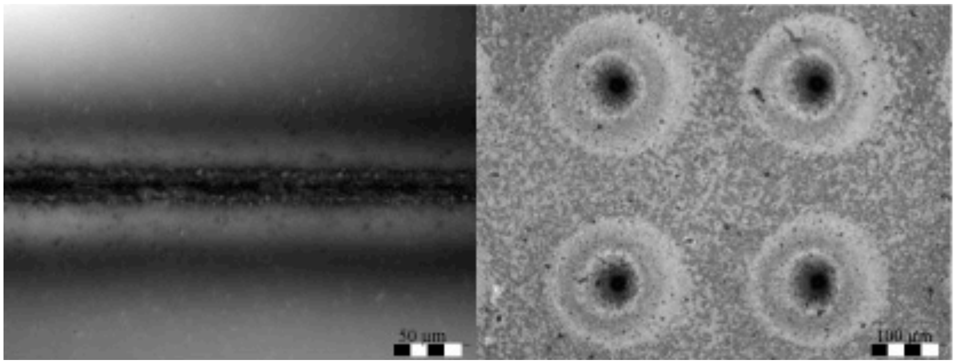

Figure 2: Optical images of a trench (left) and holes (right) ablated into the front surface

By translating the focus of the lens behind the front surface of the silicon wafer, we have confirmed that it is possible to machine the back surface of the silicon wafer without causing damage to the front surface. Notably, the morphology of the features machined on the backside is quite different from those observed when ablating the front surface. While there is sill clear evidence of melting, there is much less indication of material removal and there is almost no sign of ablation debris.

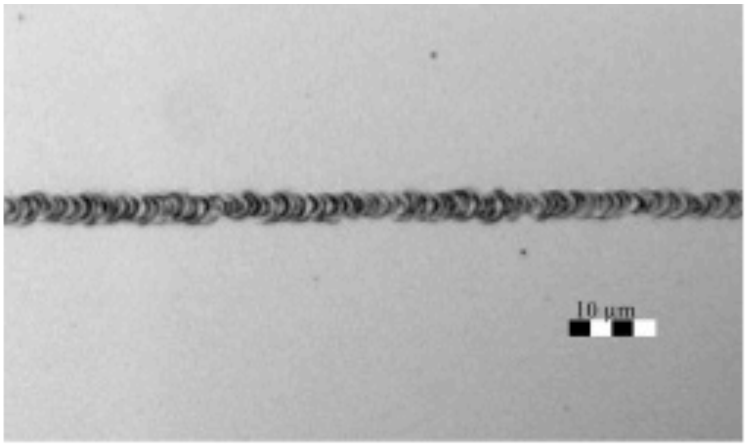

Figure 3: Image of the feature machined on the backside using 6.5 ns pulses at 1 mm/s translation speed

Discussion

These initial results are highly promising as they indicate nanosecond Tm:fiber lasers systems may offer unique possibilities for materials processing of semiconductor materials. While these materials are transparent to 2 µm, there are significant differences apparent between processing in this regime relative to the machining of transparent dielectrics using nanosecond lasers at 1 µm wavelength. We are continuing to investigate the influence of parameters such as pulse duration, incident fluence/intensity, and focal geometry in order to better understand this laser-material interaction.

Acknowledgements

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