Fused Silica Substrate and Silicon Absorber Film for use in Laser Spike Annealing (LSA)

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Abstract:

Laser spike annealing (LSA), performed at various dwell times and generating various peak temperatures [1], is used to induce metastable phases in a variety of materials. An alternate LSA setup, which would allow annealing of metals and transparent dielectrics, requires the appropriate choice of a substrate, which is annealed directly, and an absorber film, which conducts heat to the material of interest. We investigate fused silica and silicon as candidates for substrate and absorber film, respectively. An Si thin-film was deposited via plasma enhanced chemical vapor deposition (PECVD) on a fused silica substrate and subjected to LSA with a CO_2 laser (10.6 μm) at various powers. LSA was performed on the glass substrate with a laser diode (980 nm) at various currents and dwell times. Profilometer measurements of the CO_2 anneals suggest Si ablation and potential substrate damage at 20.55W, as well as lesser ablation or an increase in grain size at lower powers. Laser diode annealing of the fused silica substrate caused no damage visible to the eye. Our work contributes to the development of a "universal substrate" for use in the modified laser spike annealing setup.

Summary of Research:

Laser spike annealing (LSA), performed at various dwell times and peak temperatures [1], is used to induce metastable phases in a variety of systems, such as Bi_2O_3 and $MnTiO_3$ [2]. To allow annealing of additional materials, including transparent dielectrics and metals, an alternate LSA method is in development. Annealing is performed from the substrate side of the sample, allowing an absorber film to conduct the heat to the material under investigation. Appropriate substrate and film choices will therefore withstand anneals that induce a wide range of peak temperatures and occur at different dwell times. Previous research has revealed inadequacies of sapphire substrates for LSA [3]. In this project, silicon (Si) and fused silica were investigated as potential absorber film and substrate, respectively. As peak temperature calibrations for these materials have yet to be performed using our laser setup, we explored the behavior of our substrate and film at varying laser power (or current) and dwell time.

A 100 mm diameter, 500 μm-thick fused silica wafer, polished on both sides, was purchased from the Cornell NanoScale Science and Technology Facility (CNF) and used as a substrate. Approximately 60 nm of amorphous silicon (α-Si), which crystallized to polycrystalline silicon (poly-Si), were deposited on the substrate via plasma enhanced chemical vapor deposition (PECVD) at 350°C. The deposited film exhibited a transparent, pink-purple color. The absorber film candidate was annealed with a CO_2 laser (10.6 μm) at 1 ms dwell times, at power conditions of 20.55-6.22W. All these powers induced stripes in the thin-film visible to the naked eye (Figure 1).

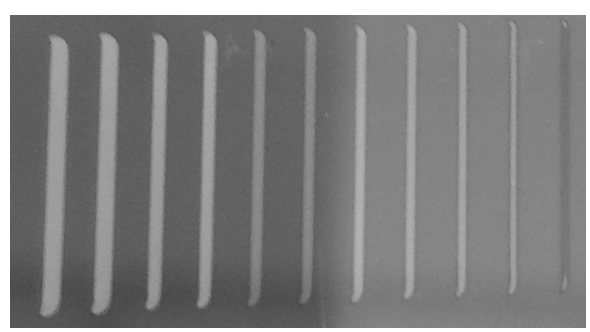

Figure 1: Annealed stripes (20.55W-6.84W, CO_2 laser) on poly-Si surface. Laser power decreases from left to right.

Stripes annealed at powers of 20.55W-10.8W appeared clear, while the film annealed at lower powers displayed a color change to light green.

To understand the physical changes that occurred in the sample during annealing, step heights between the annealed stripe centers and the surrounding thin-film were investigated using a Tencor P10 Profilometer. Stripes annealed at powers of 20.55W and 18.43W, respectively, which appeared clear to the naked eye, evidenced film ablation under profilometer examination. A step height of 1.097 μm (1097 nm) in the former stripe suggests both complete ablation of the 60 nm film and CO_2 laser damage to the glass substrate beneath. This conjecture is supported by an additional set of anneals, in which CO_2 laser annealing at 20.55W directly onto the fused silica produced a damage stripe (Figure 2). The second annealed stripe (18.432W) evidenced 425Å (42.5 nm) between stripe center and unannealed film. This indicates a relatively complete ablation of the thin-film by the CO_2 laser.

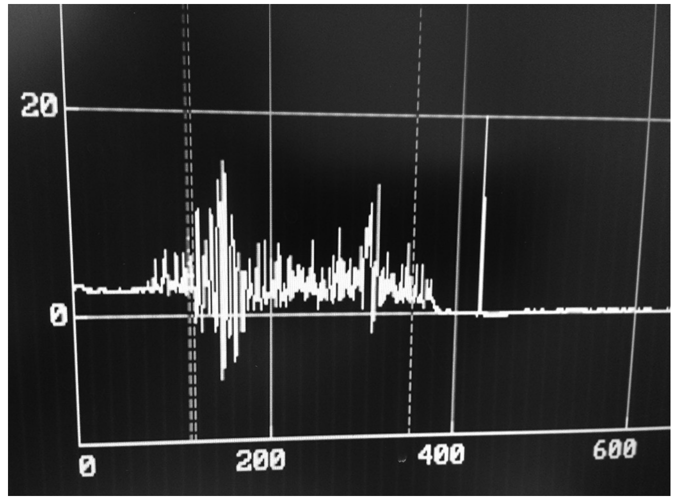

Figure 3: P10 Profilometer measurement of LSA stripe (10.267W, CO_2 laser) on silicon thin-film. Scale: vertical axis: x100Å, horizontal axis: µm.

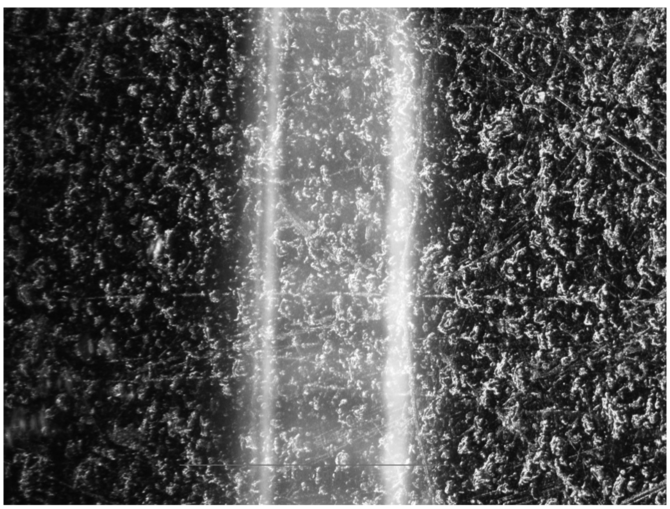

Figure 2: Dark-field view of LSA stripe (20.55W, CO_2 laser) on a fused silica substrate.

Two of the green-colored stripes were also examined with the profilometer. Both the fifth (10.267W) and sixth (9.724W) stripe measurements displayed large amounts of noise in their respective annealed regions. As a result, the Ra (roughness average) was parameter of importance. The fifth stripe had an Ra of 198Å, while the sixth evidenced an Ra of 156.4Å. Thus, a lower roughness average is observed at lower laser power. Noise observed in the profilometer measurements of the stripes may indicate that the poly-Si has transformed from small-grain to large-grain during the annealing process (Figure 3).

To further examine fused silica's potential as an LSA substrate, the glass was directly subjected to laser spike annealing with a laser diode (wavelength 980 nm). A set of five anneals (5 ms dwell times), with currents increasing from 63.58 Amps to 100.22 Amps, caused no damage to the substrate visible to the naked eye. To perform subsequent anneals at 100 Amps or below, the dwell time was increased. Two anneals, performed at 87.68 Amps and 97.76 Amps, respectively, with dwell time 10 ms, also caused no visible damage to the glass substrate. A further two anneals at 20 ms dwell times and currents of 82.5 Amps and 85.99 Amps, respectively, produced the same result.

We have studied the behavior of fused silica substrates and silicon absorber films under CO_2 and laser diode laser spike annealing. The absence of visible laser-induced damage from the laser diode suggests fused silica is a promising substrate for laser diode LSA. However, this substrate is susceptible to damage from CO_2 lasers, even at relatively low powers. PECVD deposition of α-Si should be performed at the standard 200°C, to prevent premature crystallization and allow for a true study of amorphous silicon as a potential absorber film. Our work contributes to the development of a "universal substrate" for use in the modified laser spike annealing setup.

References:

[1] R. Bell, et al. ACS Comb. Sci. 18, 548 (2016).

[2] R. Bell, Ph.D. thesis, Cornell University (2017).

[3] H.-L. Huang, et al. Cornell NanoScale Science and Technology Facility Report, http://www.cnf.cornell.edu/doc/2017cnfRA/2017cnfRA_222.pdf (2017).