

UV-femtosecond laser ablation of SrTiO₃ single crystals

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introduction

We have investigated the ablation behavior of single crystal SrTiO₃ <100> with focus on the influence of the pulse duration at a wavelength of 248 nm. The experiments were performed with Krf-excimer lasers with pulse durations of 34 ns and 500 fs, respectively. Femtosecond-ablation turns out to be more efficient by one order of magnitude and to eliminate the known problem of cracking of SrTiO₃ during laser machining with longer pulses. In addition, the cavities ablated with femtosecond pulses display a smoother surface with no indication of melting and well-defined, sharp edges. These effects can be explained by the reduced thermal shock effect on the material by using ultrashort pulses.

results & conclusions

Comparison of UV-ns and -fs ablation

→ Ablation yield for femtosecond ablation is significantly higher (Figure 1)

→ Ablation threshold (multi pulse) for femtosecond pulse durations is one order of magnitude lower compared to the nanosecond results (see table below)

→ The lower threshold fluence and enhanced ablation yield are both due to the fact that for sub-picosecond UV pulses the laser energy is deposited within the optical penetration depth of approx. 13 nm while it spreads, via thermal diffusion, into a much deeper volume during nanosecond irradiation (Figure 2).

Pulse duration	Ablation threshold (mJ/cm ²)	
	Single pulse	Multi pulse
34 ns	0,6	0,3
500 fs	0,15	0,044

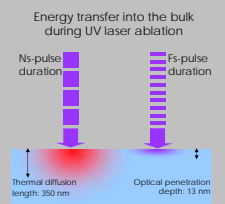


Figure 2. Lower threshold fluence and enhanced ablation yield for fs pulses is due to the fact that the laser energy is just deposited within the optical penetration depth

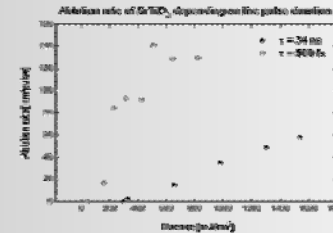


Figure 1. Comparison of the ablation rate for a wavelength of 248 nm at pulse durations of 34 ns and 500 fs, respectively

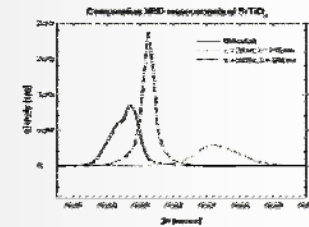


Figure 3. X-Ray diffraction (XRD) measurements have been carried out after exposure of the samples with fluences below the multi pulse ablation threshold. The graph of the untreated surface is juxtaposed with results from areas irradiated with femto- and nanosecond pulses. Sample areas exposed to nanosecond pulses display a shift of the diffraction peak to the right indicating compressive strength. The shift resulting after femtosecond irradiation is much smaller indicating the lower mechanical load on the material.

experimental

Laser Systems:

Krf-Excimer laser (LPX 200, Lambda Physik)

Distributed feedback dye laser system pumped and amplified by a Krf-Excimer laser

Pulse duration: 34 ns
Wavelength: 248 nm

Pulse duration: 500 fs
Wavelength: 248 nm

Setup:

An iris aperture was imaged by means of a single lens.

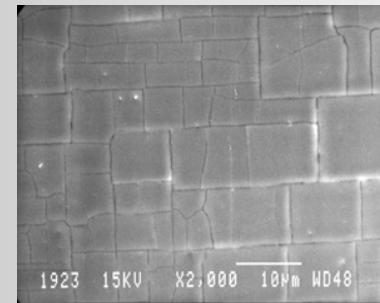
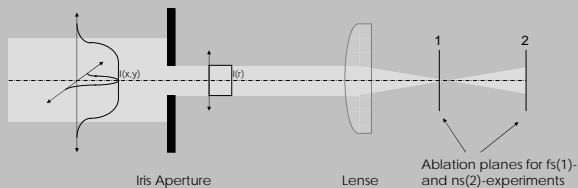


Figure 4. Formation of cracks along the crystallographic axis during ns ablation due to shockwave excitation in the material. On the femtosecond time scale the ablation process is faster than the energy transfer into the bulk material. The energy deposited by the laser pulse is used for the material removal and carried away by the ablation products. → Thermal shock is avoided.

→ For ns ablation at a fluence of 0,2 J/cm² darkening of the irradiated area occurs after a single pulse, which may be due to a chemical modification of the surface region. In the case of fs ablation no darkening could be observed

Figure 5. Cavities in SrTiO₃ ablated with a wavelength of 248 nm and a pulse duration of 34 ns (A) and 500 fs (B), respectively. The spots have been exposed with 100 pulses at a fluence of 3,3 J/cm² for the nanosecond and 0,34 J/cm² for the femtosecond experiments. For the nanosecond pulses the corrugated shape of the bottom area most likely results from the annealing of the cracks (Figure 4) by melting and resolidification of the material. The bottom shows pores which is also an evidence of a melting process. In comparison to ablation with femtosecond pulses, the surrounding area is more affected due to the higher heat transfer into the bulk. The SEM micrograph of the femtosecond ablated structure shows no indication of melting. It exhibits sharp edges and less debris deposited at the surrounding area.

