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# Femtosecond laser-generated shockwaves in transparent media: Experiments and Simulation

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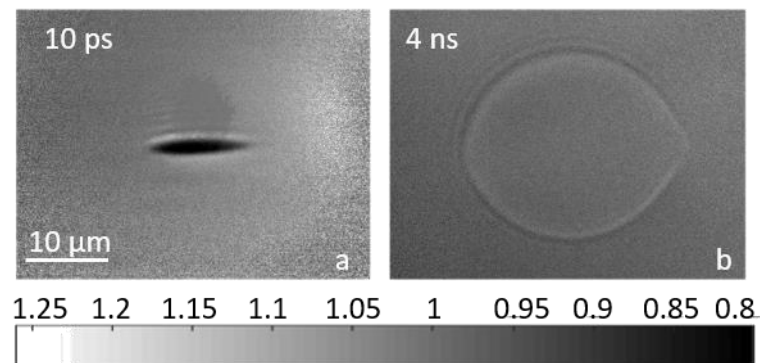
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Interaction of intense femtosecond laser pulses with transparent materials has been a topic of growing interest in the past decades [1]. Among others, two features are particularly attractive. First, unprecedented material processing quality can be achieved as very small amount of energy is sufficient to induce the desired modification. Second, owing to localization of the laser peak intensity and the threshold-dependent nonlinear interaction, three-dimensional processing of transparent materials becomes possible. Although a growing number of applications exist [2], several limitations are present. As an example, there is an everlasting need to minimize the laser affected volume and thus avoid unwanted crack propagation or mechanical defect generation during in-bulk material processing.

In this paper, we study the thermomechanical coupling of laser energy in air. We use a 380-fs commercial laser system emitting at 1.03  $\mu\text{m}$  to perform our experiments. Focusing down to a 1.5  $\mu\text{m}$  spot diameter we achieve laser intensities up to  $10^{15}$   $\text{W}/\text{cm}^2$  that are sufficiently high to transform almost any insulator into an absorber. Following the laser energy deposition, an important gradient of pressure and temperature builds up that results in a violent decompression through emission of a shockwave. A home-built time-resolved, high-resolution transmission microscope with visible light allows direct observation of both the plasma formation (Fig. 1-a) and the propagation of the shockwave in space (Fig. 1-b). Our technique allows measurement of the shockwave propagation speed at early delays with values reaching up to 5000 m/s. Knowing the shockwave propagation speed, we use the conservation laws and the equation of state to theoretically estimate the pressure of the waves. To provide a larger picture of the interaction, we complement with measurement of the transmitted, excitation-pulse energy after the sample thus associating absorbed laser energy density to emitted shockwave characteristics.

We will discuss the results and limitations of our approach but also possible implementation for measuring laser-driven dynamic stress fields in the case of transparent solids.



**Fig. 1** Experimentally obtained transmission images in air following excitation by a single 5- $\mu\text{J}$  femtosecond pulse. Two delays after the arrival of the pulse are displayed: 10 ps (a) and 4 ns (b).

## References

- [1] R. R. Gattass and E. Mazur, "Femtosecond laser micromachining in transparent materials," *Nat. Photonics*, vol. 2, no. 6, pp. 378–379, 2008.
- [2] K. Sugioka and Y. Cheng, "Ultrafast lasers-reliable tools for advanced materials processing," *Light Sci. Appl.*, vol. 3, no. 390, pp. 1–12, 2014.