Guiding Femtosecond Laser Pulses by Copper Capillaries for Laser-Driven Plasma Wakefield Acceleration

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Abstract: Transmission of 50fs laser pulses through 20-mm-long, 50µm wide copper capillaries is measured to be 70% for intensities up to 10^{17}W/cm^2, but reduces after hundreds of shots because of solid plug formation inside the capillary.

Guiding femtosecond laser pulses by metallic or plasma-walled capillaries is studied in the context of laser-driven plasma wakefield acceleration. In common with other plasma-based acceleration techniques, this method has potentialities of reaching GeV scale energies of accelerated particles in several centimeters. Thanks to keeping the drive laser pulse tightly focused, the capillary could make possible the efficient acceleration with laser pulses of modest (sub-TW) peak power.

Initial experiments [1] on propagation of high-intensity, high-contrast ($<10^8$), 50 fs laser pulses through triangular copper capillaries indicate that the relative transmission through 20-mm-long, about 50 µm wide capillaries is as high as 70% for input intensities up to 10^{17}W/cm^2 (Fig.1).

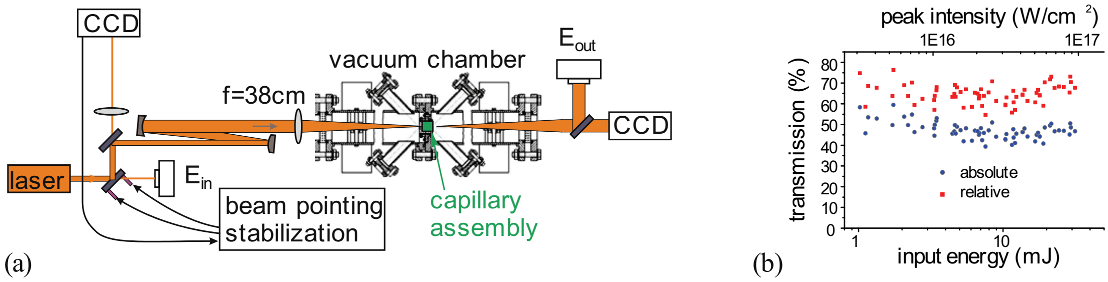

Fig.1. (a) The experimental setup for measuring capillary transmission; (b) the measured dependence of capillary transmission on the pulse energy or peak intensity.

The measured reflectivity of a plane copper plate in vacuum, helium, and air in the intensity range of 10^{10}–10^{17} W/cm^2 (Fig.2) suggests that capillary waveguides can efficiently guide laser pulses of intensities up to about 10^{19} W/cm^2 on the capillary axis (that corresponds to 10^{17} W/cm^2 on the walls).

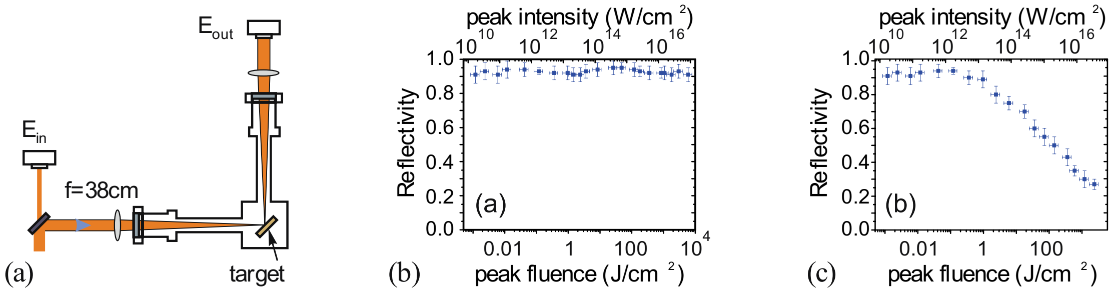

Fig.2. The experimental setup for measuring copper reflectivity (a). The measured dependence of the copper reflectivity on the incident peak intensity and fluence at (b) vacuum (10-5 bar) and (c) air conditions.

The transmission efficiency reduces to zero after several hundreds of shots because of solid plug formation inside the capillary. The suggested theoretical model indicates that plug formation is a universal effect, which must take place in any narrow tube subject to ablation under the action of many short laser pulses. A simple physical effect underlies plug formation. The material travels in both directions along the capillary. Roughly, half of the ablated material moves forward and sees a week oncoming stream, as there is almost no ablation in downstream areas. This unbalanced material flow (permanently supported by the repeating pulses) results in material accumulation at some place and formation of a plug there. Note that the model predicts plug formation even with no account of specific volume increase. In the experiments, we see that the re-deposited material is porous and thus has a larger volume, which additionally favors capillary blocking.

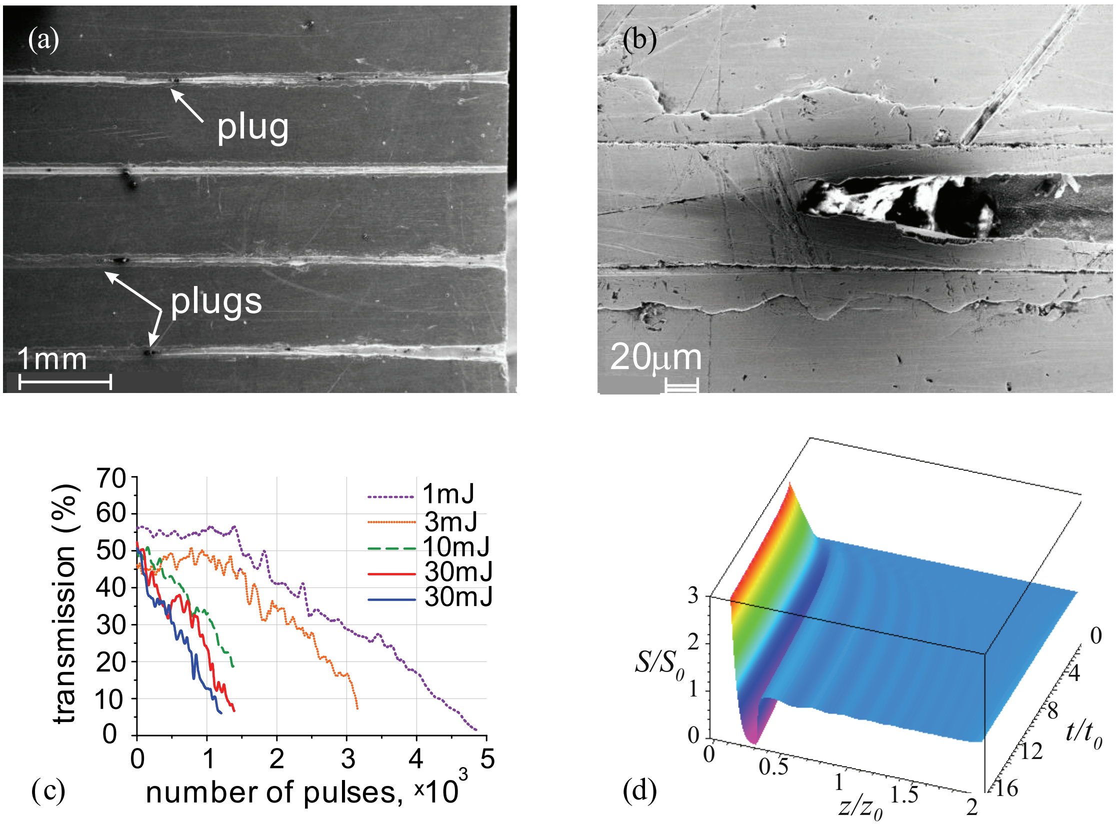

Fig.3. Scanning electron microscope images of the plugs in capillaries (a) and the enlarged origin of a plug (b). Reduction of the absolute transmission with the number of transmitted pulses for different pulse energies (c). Simulated evolution of the capillary cross-sections S versus time t and distance to the entrance z.

Numerical simulations with LCODE [2] indicates that acceleration of test electrons in capillaries is as efficient as in the unbounded plasma.

References

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[2] A.P.Sosedkin, K.V.Lotov, "LCODE: a parallel quasistatic code for computationally heavy problems of plasma wakefield acceleration," Nucl. Instr. Meth. A (2015), http://dx.doi.org/10.1016/j.nima.2015.12.032i