Morphology of glass irradiated with femtosecond laser pulses at variable repetition rates

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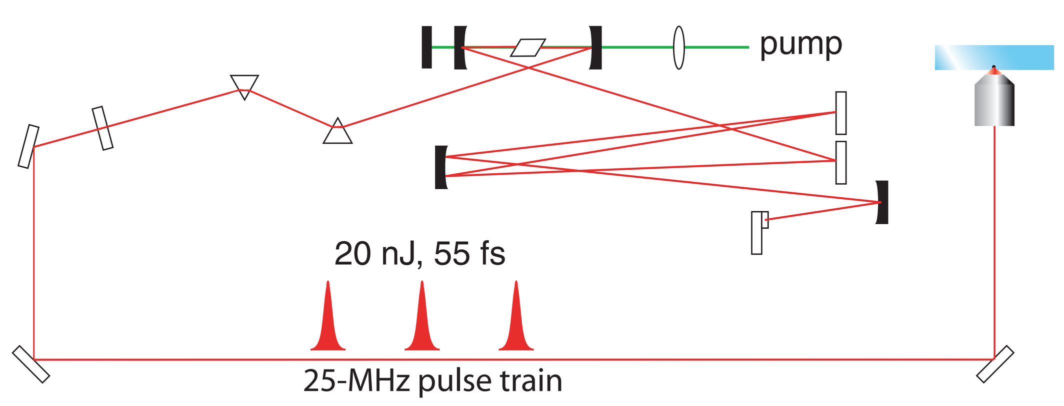
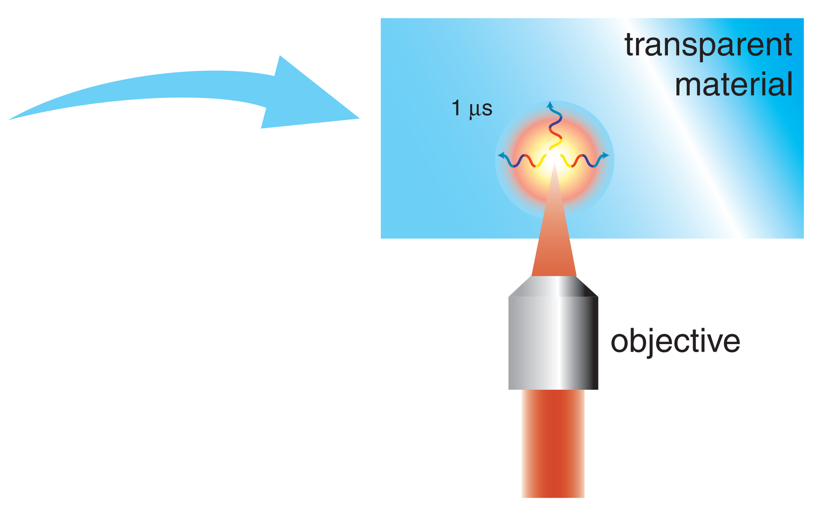
Introduction

Tight focusing of femtosecond pulses results in extremely high intensities even at moderate pulse energies. The high intensity at the focus can lead to nonlinear absorption of laser energy in transparent materials.

At MHz pulse repetition rates, the time interval between pulses is smaller than the heat diffusion time; energy therefore accumulates in the focal volume, heating and melting a micrometer-sized region in the bulk of the material.

Nonuniform cooling of the melted volume results in a permanent change in index of refraction. We exploit this index change to fabricate waveguides.



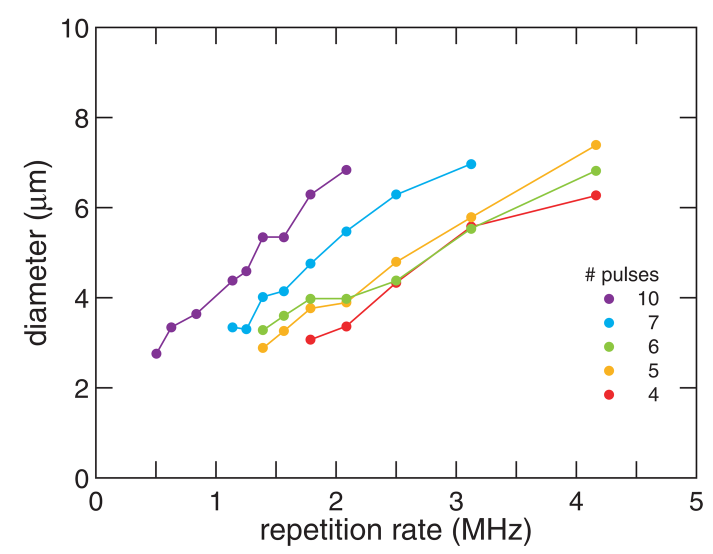


By extending the cavity of a standard Ti:sapphire laser oscillator, we generate a 25-MHz pulse train of 20-nJ pulses — enough energy to produce nonlinear absorption.

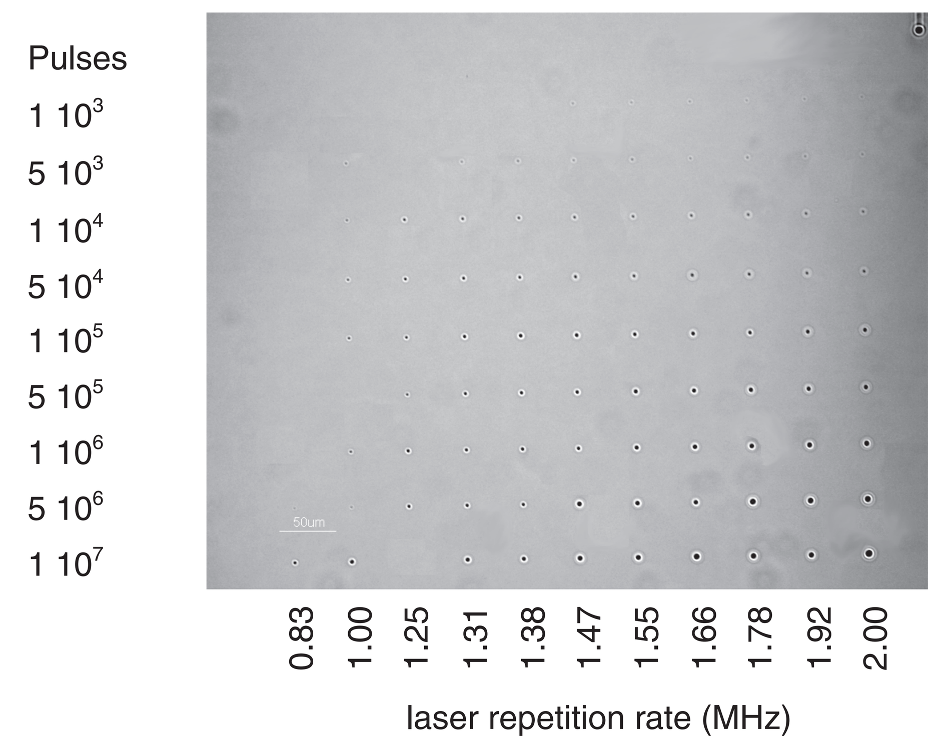
Because a thermal mechanism is responsible for the index change, the modified region is larger than the focal volume. The structurally modified region can be made large enough to guide light.

Pulse packets

Two parameters define the mode field parameter: index of refraction profile and waveguide diameter. By changing the duty cycle for a given repetition rate we can control the diameter of the waveguide. The same core diameter can be obtained with many combinations of pulses per packet and repetition rate.



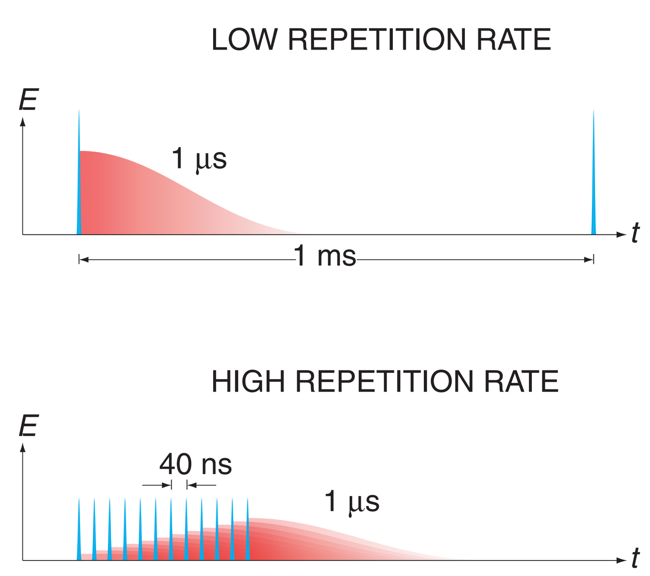
Repetition rate dependence of the waveguide diameter in Corning 0215 for various number of pulses in packet.. Pulse energy at sample is maintained at 5.5 nJ, focusing 1.4 numerical aperture lens, translation speed 1 mm/s.



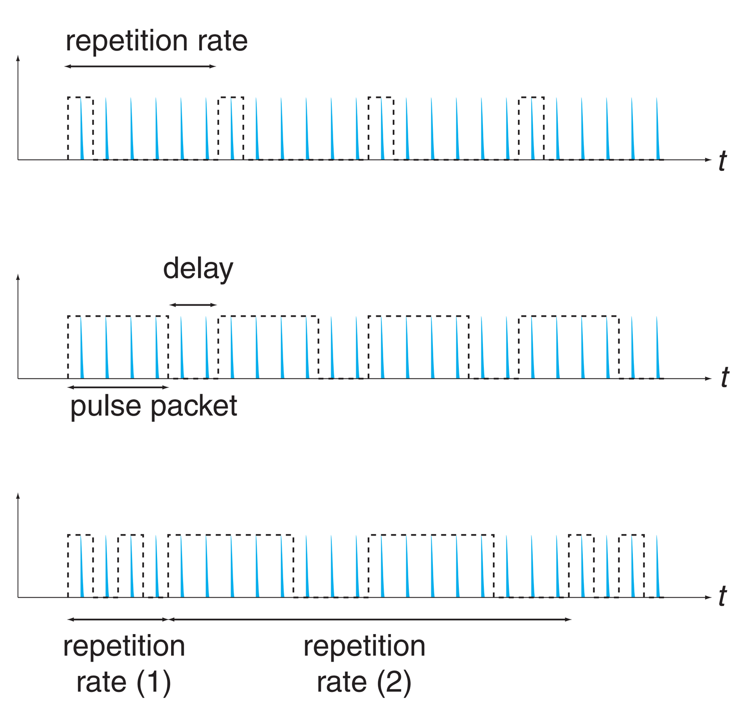
Corning 0215 slide irradiated with increasing number of laser pulses per spot at different repetition rates. For low number of laser pulses modification still occurs. The number of pulses inside each laser packet is equal to 10. Individual laser pulse energy is constant throughout (1.4 N.A. focusing).

Repetition rate control

Transparent materials have been micromachined using femtosecond systems with very different pulse energies and geometries. Both low repetition rate (< MHz) and high repetition rate (> MHz) can be used for micromachining. For the case of high repetition rate, we investigated the dependence on the number of pulses within a "packet" arriving at a given repetition rate.

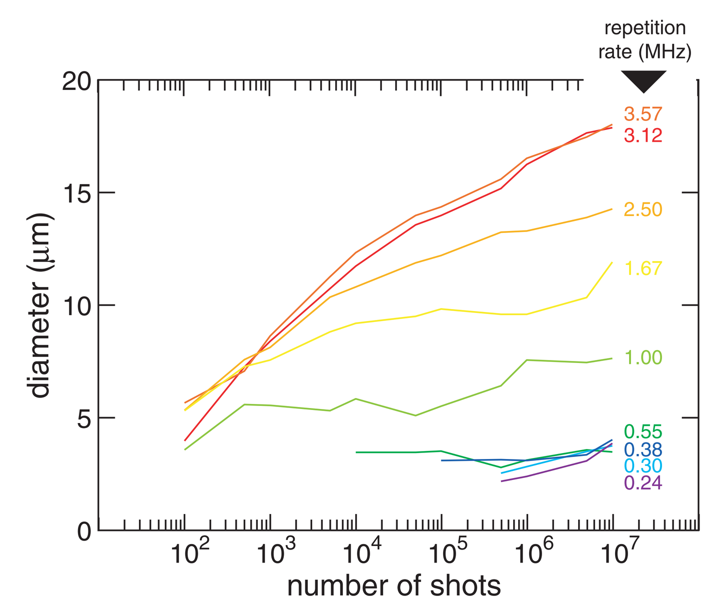


Energy deposition by an amplified laser system (1 kHz) and by an oscillator (25 MHz). Yellow indicates optical pulses and red indicates thermal energy.

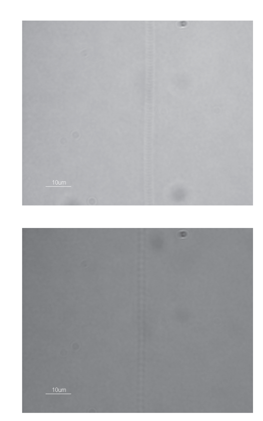


Repetition rate limit

Oscillator-only machining involves the accumulation of thermal energy from pulse to pulse. We investigated the lower limit for machining in Corning 0215, a borosilicate glass. For pulse-to-pulse rates higher then 1 MHz, accumulation occurs.



Diameter in Corning 0215 for various laser repetition rates with laser packets of 5 pulses. Pulse energy at sample 4.8 nJ, in 60 fs.



Optical image of a modulated waveguide. Modulations are induced by changing from one laser repetition rate to another or by changing the number of pulses inside a packet.

Future directions

We are investigating the use of variable repetition rates for generating embedded Bragg gratings. Additionally we are mapping the spatial index profile as a function of both repetition rate and number of pulses.

Acknowledgements: We would like to thank Jonathan Ashcom of MIT Lincoln Laboratories, Masanao Kamata from Keio University. This work is supported by MRSEC and the National Science Foundation.