Pearl-chain waveguides machined with a femtosecond high-energy oscillator

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Femtosecond laser are widely used for the micromachining of transparent bulk material and especially for the fabrication of waveguides in fused silica, BK7 and doped glasses.[1] These waveguides normally have a refractive index change up to 10^{-3} and depending on the focusing conditions show cross-sections of circular to very elliptical shape. In attempt to enhance the refractive index change bigger, we used a high-energy oscillator[2] without any further amplification stage at the repetition rate of 10.7MHz and 26fs pulse duration. The oscillator can provide pulses up to 150nJ, allowing us to work with very relaxed focusing conditions (an aspheric lens with NA 0.55). The laser is focused 250µm into the sample and then the sample is translated with speeds up to 10mm/s transversally to the incident light. We were able to produce smooth waveguides with refractive index change of 10^{-4} and normal guiding properties, but big coupling losses due to the very elliptical cross-section (1:15). The required pulse energies for this process were found to be 24-26nJ, but we also found a sharp threshold at 27 nJ where completely new waveguides could be produced. These pearl-chain waveguides consist of small (diameter ~3-5µm) spheres of modified material aligned along the writing path of the laser; Fig.1. The change of the refractive index was measured by QPm microscopy and further retrieval of the phase to be higher than 10^{-2}, which was later confirmed by simulation of the mode field diameter. The waveguide properties were examined at 670nm and 1559nm and it was found that the coupling is very easy. At 670nm we observed multimode guiding, but at 1559nm the waveguides work in the single mode regime.

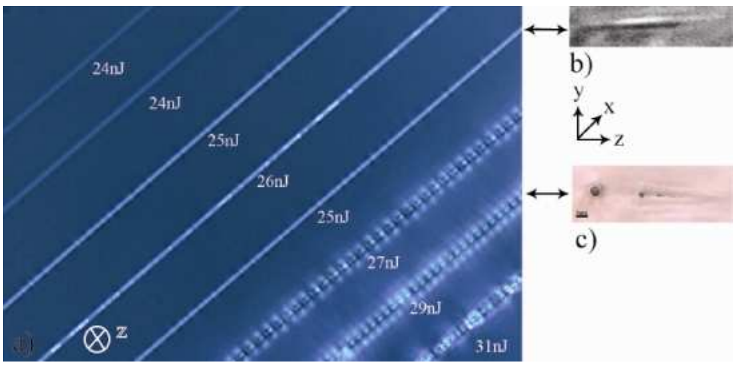

Figure 1: a) Several waveguides written at different energies, the laser was always incident from the z-direction, b) sideview of smooth waveguides and c) sideview of the pearl-chain waveguides

These new waveguides can be produced only in a very small range of pulse energies. At 31nJ the structures are already becoming irregular and the guiding properties are getting worse. The material seems to be strongly damaged and the pearls are developing into voids.
With regular pearl-chain waveguides we were also able to produce different types of couplers and we are further investigating the possibility to write very strongly bent or even rectangular shaped waveguides, which would open a new field in design of chips and sensors, based on light guiding.

1.) K. M. Davis, K. Miura, N. Sugimoto, and K. Hirao, OPTICS LETTERS Vol. 21, 1729-1731
2.) A. Fernandez, T. Fuji, A. Poppe, A. Fürbach, F. Krausz and A. Apolonski, OPTICS LETTERS Vol. 29, 1366-1368