Mechanisms of femtosecond laser nanoprocessing of biological cells and tissues

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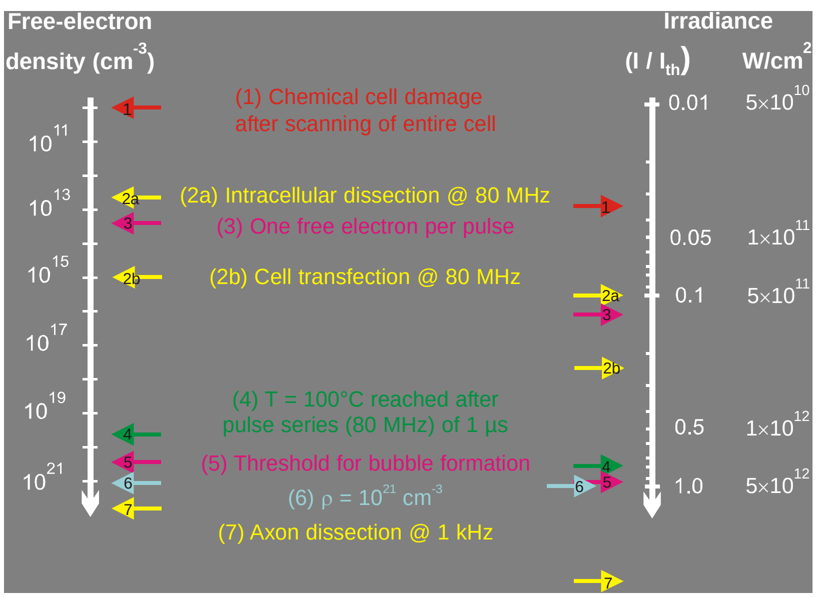
We investigated the working mechanisms of femtosecond laser nanoprocessing in biomaterials with oscillator pulses of 80 MHz repetition rate and with amplified pulses of 1 kHz repetition rate. Plasma formation in water, the evolution of the temperature distribution, thermoelastic stress generation, and stress-induced cavitation bubble formation were numerically simulated for NA = 1.3 and the outcome compared to experimental results. Mechanisms and spatial resolution of femtosecond laser surgery were, furthermore, compared to the features of cw microbeams.

We find that free electrons are produced in a fairly large irradiance range below the optical breakdown threshold, with a deterministic relationship between free electron density and irradiance. This provides a large 'tuning range' for the creation of spatially extremely confined chemical, thermal and mechanical effects via free electron generation. Dissection at 80 MHz repetition rate is performed in the low-density plasma regime at pulse energies well below the optical breakdown threshold. It is mediated by free-electron-induced chemical decomposition (bond breaking) in conjunction with multiphoton-induced chemistry, and not related to heating or thermoelastic stresses. When the energy is raised, long-lasting bubbles are produced by accumulative heating and tissue dissociation into volatile fragments which is usually unwanted. By contrast, dissection with 1 kHz repetition rate is performed using about 10-fold larger pulse energies and relies on thermoelastically-induced formation of minute transient cavities with life times < 100 ns. Both modes of fs-laser nanoprocessing can achieve a 2-3 fold better precision than cell surgery using cw irradiation and enable manipulation at arbitrary locations.



Overall view of low-density plasma effects and breakdown phenomena induced by femtosecond laser pulses in comparison to experimental data on cell surgery.

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