Taking Advantage of Relaxation Processes in Water near Biological Surfaces

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The Mark-III Free-Electron Laser (FEL) is a short-pulsed, tunable infrared laser that has found applications in human neurosurgery and animal ophthalmic surgery. Surgeries were performed at a wavelength of 6.45 microns, where the FEL effectively ablated tissue with minimal collateral thermal damage. The Mark-III FEL is a light source based on an electron accelerator, tunable from 2-to-10 microns, that produces a burst of picosecond optical pulses at a repetition rate of 3 GHz. Tens of thousands of picosecond “micropulses” comprises a “macropulse,” with duration of 4-6 microseconds. The macropulse repetition rate is tens of Hertz. We modeled the mechanisms governing infrared tissue ablation to account for these experimental observations, highlighting the role of thermal diffusion and chemical kinetics, characterizing the key dynamics as superheated tissue water explosively vaporizing on the nanosecond time scale in parallel with the chemical kinetics of protein denaturation leading to brittle fracture. Thus the key dynamic processes occur on the ten-nanosecond time scale, leading to the prediction that picosecond pulses are not crucial and the superpulse can be replaced with a train of nanosecond pulses.

Interest has been mounting for the development of a single-wavelength laser operating near 6.45 microns, relatively compact and inexpensive, with comparable ablative properties to that of the Mark-III FEL. The superpulse structure of the Mark-III FEL, with both high-peak power and high-average power, has not been reproduced by conventional infrared laser technology. There is considerable evidence that the preferential ablative properties observed at 6.45 microns with the Mark-III FEL depends both on wavelength and pulse structure. Therefore avoiding adverse consequences on the ablative properties due to modifying the superpulse structure of the Mark-III FEL will be crucial for the development of alternative medical lasers. We have collaborated in the development of a four-stage laser system based on difference frequency mixing and stimulated Raman scattering, emitting at a wavelength of 6.45 microns with a 3-5 ns pulse duration, a pulse repetition rate of one-half Hertz, and pulse energies of up to 2 mJ. This laser system efficiently ablated animal brain tissue with little-to-no collateral thermal damage.

Comments will be made regarding experimental observations of water dynamics near DNA surfaces, summarizing observations of imprinting and apparent long-range interactions.