All-Fiber Nanosecond Laser System Generating Supercontinuum Spectrum for Photoacoustic Imaging

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Photoacoustic microscopy (PAM) research, as an imaging modality, has shown promising results in imaging angiogenesis and cutaneous malignancies like melanoma, revealing systemic diseases including diabetes, hypertension, coronery artery, cardiovascular disease from their effect on the microvasculature, tracing drug efficiency and assessment of therapy, monitoring healing processes such as wound cicatrization, brain imaging and mapping, neuroscientific evaluations. Clinically, PAM can be used as a diagnostic and predictive medicine tool; even have a part in disease prevention[1].

Parameters of the laser used in PAM, such as pulse duration, energy, PRF (pulse repetition frequency), and pulse-to-pulse stability affect signal amplitude and quality, data acquisition speed and obliquely the spatial resolution. Current lasers used in photoacoustic imaging are commercially available Q-switched lasers, low-power laser diodes, and very recently, fiber lasers with non-adjustable properties. In all of these systems, the key parameters cannot be adjusted independently of each other, bringing about certain systematic limitations on optimization of current microscopy systems. For example, microvasculature and cellular imaging require rather different laser properties. Thus, there is need for a laser system that offers largely independent control over the key parameters.

Here, we report a unique, all-fiber-integrated, fiber laser system producing nanosecond pulses covering a wavelength range of 600 nm to 1100 nm, developed specifically as a source for photoacoustic excitation. The system comprises of an oscillator (Yb-doped NOLM laser) and amplifier, which generates and amplifies nanosecond pulses respectively, an acousto-optic modulator to control pulse repetition rate and a photonic-crystal fiber to generate supercontinuum. Complete control over the pulse train, including generation of non-uniform pulse trains, is achieved via the AOM through custom-developed field-programmable gate-array (FPGA) electronics. The system is unique in terms of offering adjustability for all the important parameters over broad ranges, namely, the pulse duration (1-3 or longer ns), pulse energy (up to 10 μJ, e.g., at 50 kHz) and repetition rate (50 kHz - 3 MHz). Moreover, different photocoustic imaging probes can be excited using this single laser system thanks to its broad-spectrum output (600 nm to 1300 nm) based on supercontinuum generation. The entire system is fiber-integrated, meaning that beam propagation is waveguided in fiber everywhere, making it misalignment free and largely immune to mechanical vibrations. The laser system is robust, compact, low-cost and built using only readily available standard components.

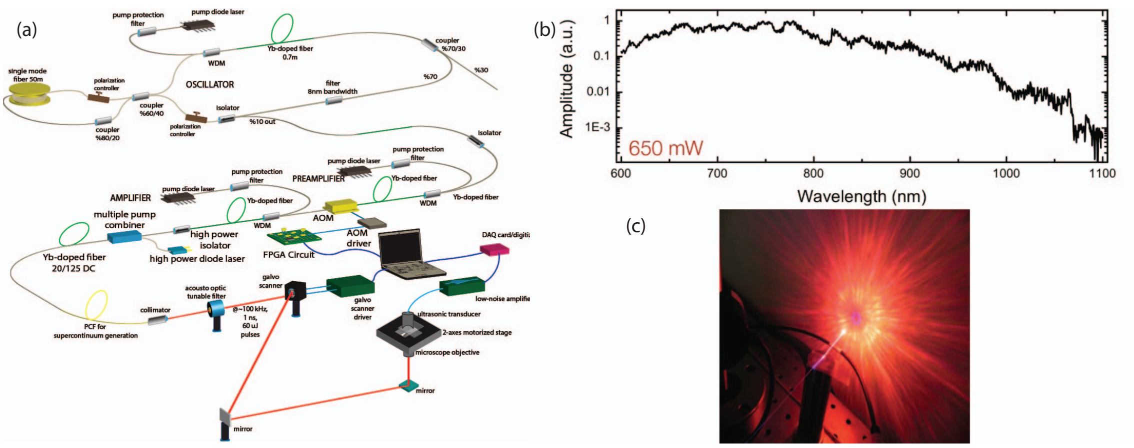

Fig. 1 (a) Fiber laser system generating supercontinuum spectrum and nanosecond pulses (b) spectrum graph of the photonic-crystal fiber output (c) photo taken at the output of PCF, different colours are visible due to supercontinuum in visible range.

References

[1] H. F. Zhang, K. Maslov, G. Stoica, and L. V. Wang, "Functional photoacoustic microscopy for high-resolution and noninvasive in vivo imaging", Nat. Biotechnol., 24, 848 (2006).