A passively mode-locked Ti:Al$_2$O$_3$ laser using a nonlinear coupled cavity

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A titanium sapphire laser is a versatile laser with wide tunability (670 nm to 1100 nm) and high power capability. Researchers at MIT have recently demonstrated tunable femtosecond pulse generation in a titanium sapphire laser using a passive nonlinear external cavity. The coupled-cavity titanium sapphire laser provides a versatile source at a significant reduction in cost and complexity over short pulse dye laser technology.

The laser consisted of a cavity containing the gain medium and frequency-selective optics coupled to a second cavity of equal length containing an optical fiber. The interferometric pulse combining effect of the two cavities plus the self-phase modulation nonlinearity in the optical fiber produced stable, short pulse operation and no external active modulation was required. Pulse durations as short as 200 fs were generated.

The use of a nonlinearity in coupled cavities under the special conditions of soliton propagation resulted in shortened pulses from a mode-locked laser. More recently, it was predicted that a nonlinearity in coupled cavities was a general technique for shortening pulses from mode-locked lasers. Several groups have demonstrated this technique experimentally and achieved dramatic improvements in mode-locked performance. These demonstrations required auxiliary modulation (i.e., synchronous pumping or active mode locking) to start the laser, which contributed to system complexity. The titanium sapphire laser system extends the previous techniques, because short pulses are generated spontaneously without external modulation.

The coupled-cavity titanium sapphire laser is shown schematically in the figure. Without the external cavity, the laser operates as a conventional tunable, continuous laser. The laser produced 1 W of continuous output with 8 W of argon-ion laser pump input using a 15% output coupler. The external cavity consisted of a beam splitter, an optical fiber, and a retroreflecting end mirror. To obtain short pulses, the round trip times of the two cavities must match within the pulse duration and phase stability maintained to within a fraction of a wavelength. This length difference was controlled by using a piezoelectric translator and an electronic feedback stabilization circuit. With the laser designed for mechanical stability and active length control, the laser power and output pulse duration were very stable.

The titanium sapphire laser generated a pulse train of 1.5-ps pulses at an 80-MHz repetition rate with an average power of 250 mW for 5 W pump. The spectrum of the pulses was significantly broader than the Fourier transform limit because of dispersion introduced by the optical fiber in the external cavity. Using a diffraction grating pair, the dispersion or frequency chirp in the pulses could be compensated to yield pulse durations as short as 200 fs with a nearly transform limited time-bandwidth product. The laser was tuned from 740 nm to 800 nm, with a tuning range limited by the output coupler. In principle, the laser should be tunable over the entire titanium sapphire wavelength range by suitably changing optics and increasing the pump power.

A novel aspect of this work is the self-starting behavior of the mode locking. Self-starting implies that intensity spikes occur that produce sufficient self-phase modulation in the optical fiber to access the region of short-pulse operation. The likely cause of the intensity spikes that seed the short pulse generation is longitudinal mode beating.
Since the laser mode locking was self-starting, short pulse generation was possible without active modulation or synchronous pumping, which require expensive and extremely stable radiofrequency electronics for driving acousto-optics. The wide tunability of this system, its use of solid-state, room-temperature gain medium, and its relative simplicity and low cost suggest that this technology will be an attractive alternative to short-pulse dye laser systems in this wavelength range.

REFERENCES

High power, long life continuous-wave monolithic laser diode arrays


Multistripe monolithic AlGaAs laser diode arrays show considerable promise as sources of high power, high efficiency narrow bandwidth optical energy. Examples of applications include: a) optical pumping of solid state laser media, b) infrared illumination, c) laser soldering, and d) eye surgery. Power levels of 38 W have been demonstrated at room temperature under continuous-wave (cw) conditions for twenty 10-stripe lasers spaced along a 1 cm bar (2 mm total aperture width). We report cw operation up to 76 W and 55 W from 1 cm laser diode arrays with aperture widths of 3 mm and 2 mm, at heatsink temperatures of 0°C and 23°C, respectively. We also show that a projected lifetime in excess of 5,000 hours is obtained at 10 W at 20°C heatsink temperature.

Three types of device structures have been investigated: 20×10, 15×20, and 30×10 structures. The 20×10 structures have twenty 10-stripe lasers spaced on 500 µm centers, each occupying 100 µm of the facet length. In this case, 20% of the bar is electrically pumped for laser emission (20% packing density). The 15×20 and 30×10 structures have fifteen 20-stripe, and thirty 10-stripe lasers, respectively. In either case, 30% of the bar is used for emission (30% packing density). The laser structures were grown by metalorganic chemical vapor deposition (MOCVD) and employed single quantum-well separate confinement heterostructures (SQW-SCH).

Completed devices were tested under cw conditions at 0°C. A plot of output power versus current for one of the devices with a 30×10 structure is shown in the figure. The threshold current was 8 A and the slope efficiency was 1.0 W/A up to approximately 65 W of optical power. The