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# High energy passive Q-switching of an erbium fiber laser using a nonlinear liquifying gallium mirror

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It has been recently reported that the reflectivity of a gallium:glass interface becomes strongly nonlinear at temperatures close to, but below gallium's melting point of ~30 °C. The nonlinearity is attributed to a surface-assisted, optically-induced structural phase transition from the stable phase of solid gallium (α-gallium) to some other, as yet unidentified, metastable phase of higher reflectivity. It has been observed both in the visible and the near infrared, and characterised fully at 1550 nm [1]. Optical intensities of ~1 kW/cm$^2$ are sufficient to change the optical reflectivity of a gallium:glass interface from 50% to 65% at 1550nm, with a turn-on time shorter than 10 ns, and temperature dependent turn-off time in the range 10-1000 ns.

Initial experiments [2] had shown that this nonlinearity could be used for passive Q-switching of an erbium fiber laser ring cavity. Using a 15m cavity and a fiber butt-coupled gallium mirror we obtained 1 - 2 µs pulses with peak powers of 0.5 W. Whilst this was an important result, the first practical demonstration of the concept, the laser performance itself was not particularly impressive. In this paper we present more recent results with a more optimized cavity which show that liquefying gallium mirrors can be used to generate much shorter pulses of much higher intensity and indeed give comparable results to those achieved with state-of-the-art semiconductor saturable absorbers.

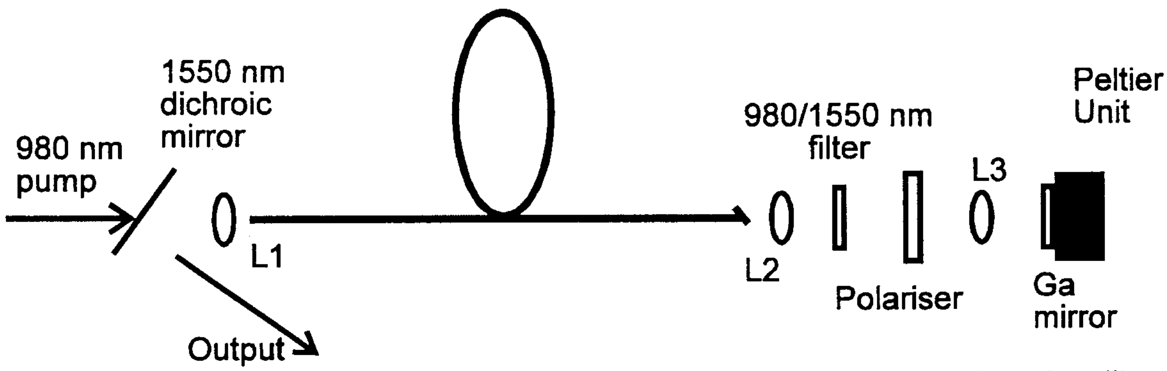


Fig. 1: Schematic of the Q-switched laser cavity, employing a large mode area erbium fiber and a gallium mirror

Our laser cavity is shown in Fig. 1. The erbium-doped fiber we used was 70 cm long and had a relatively large mode area of 300 µm$^2$ (versus 50 µm$^2$ in our previous experiments) providing greater energy storage in the cavity. The pump energy to our system was provided by a 1.6 W Ti:sapphire laser and launched into the cleaved end of the active fiber. This end acted also as the output mirror with a 4% Fresnel reflection back into the laser cavity. The other end of the fiber was angle polished to eliminate any back reflection from the fibre end. The emerging beam was collimated with a lens L2 (f = 15mm) and passed through a 980/1550 nm pump-rejection filter and polariser before being focused with a second lens L3 (f = 4.5mm) on the gallium mirror which defined the rear mirror for the Fabry-Perot cavity. The spot size on the mirror was ~30 μm². The nonlinear mirror was formed by pressing a glass slide against a thin film of initially molten gallium, which was in direct thermal contact with a Peltier unit. The Peltier unit provided stabilization and control of the temperature between 10 and 35 °C, whilst temperature readings were available from a thermocouple with a precision of 0.1 °C.

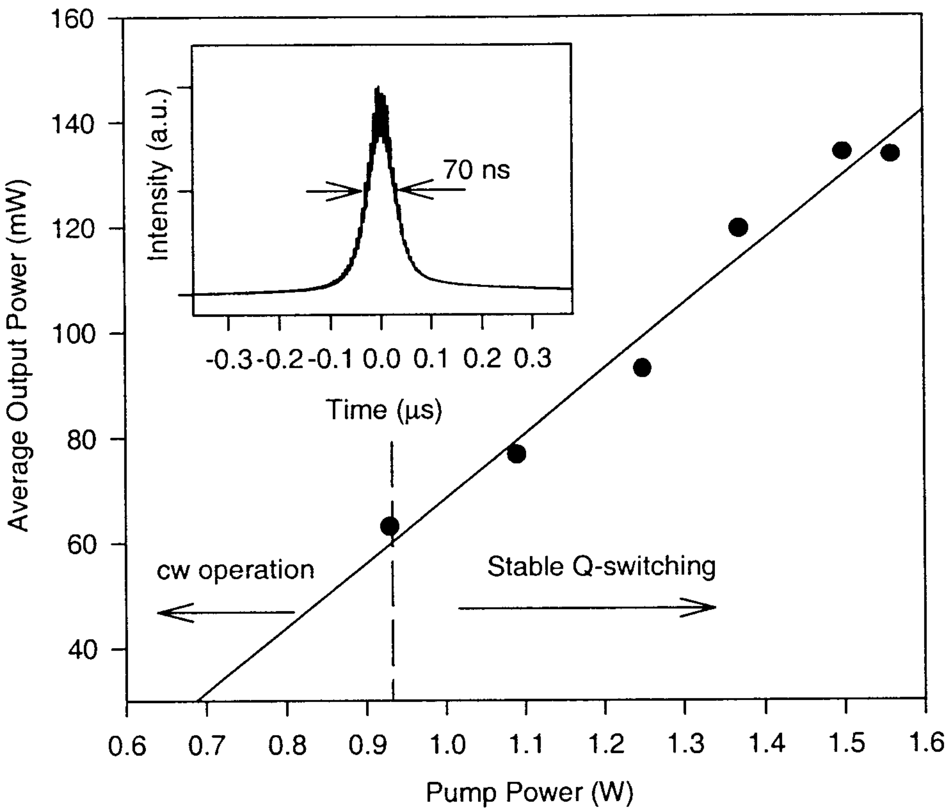


Fig. 2: Laser input/output characteristic for the Q-switching regime and typical 70 ns pulse of 70 W peak power (inset)

The output beam was separated from the pump with a dichroic mirror. Q-switching self-started typically giving 70 ns pulses with ~6 μJ pulse energies (Fig. 2 inset). A laser characteristic is shown in Fig. 2. The threshold for Q-switching operation was 0.93 W. Below this threshold the laser operated in a cw mode. The pulse repetition rate varied from 14 to 25 kHz, increasing with pump power (Fig. 3). Q-switching operation could be maintained for a wide range of temperatures. The pulse characteristics would remain almost unaltered as temperature ranged from 10 to ~25.5 °C. Above this temperature, pulsing would become unstable, exhibiting higher repetition rates in general, and would not be maintained for long periods of time. Once the temperature decreased back below this temperature, stable Q-switching would again self-start.

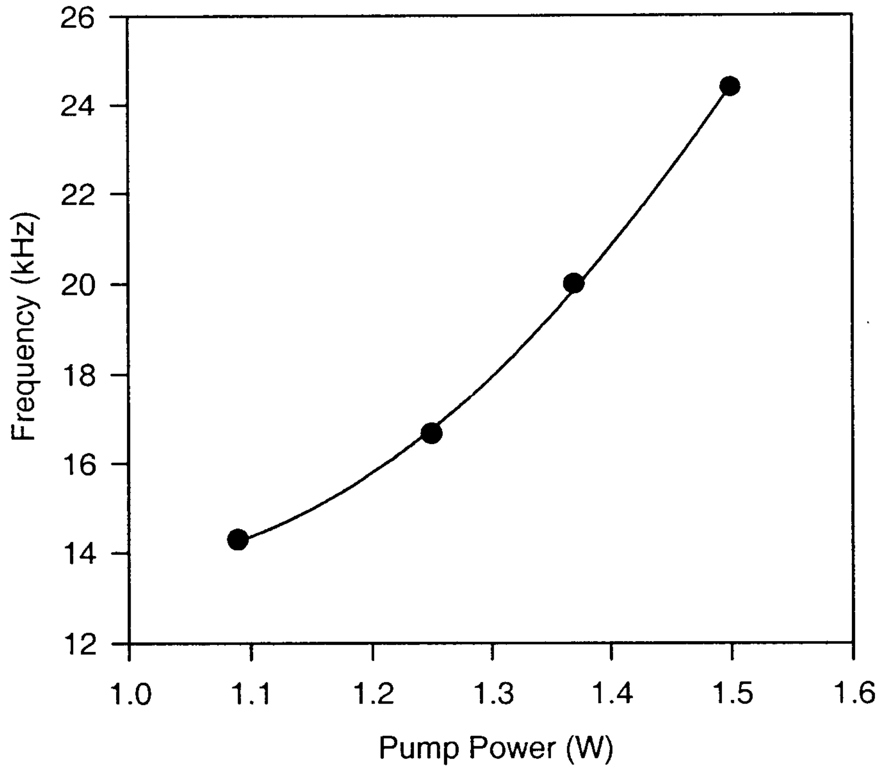


Fig. 3: Dependence of the repetition rate of the Q-switched pulses with pump power

In earlier experiments the same cavity was Q-switched with a state-of-the-art semiconductor saturable absorber mirror (SESAM) in the place of the gallium sample [3]. 65 ns pulses were obtained with 4.9 μJ pulse energy in this instance. These results are essentially equivalent to those obtained with the gallium mirror, with the obvious advantage that gallium mirrors are cheap and readily obtained and can be used over a far broader spectral bandwidth due to the exceptionally broadband nature of the nonlinearity. Thus, we expect similar mirror performance in the whole spectral range from at least 630 to 1550 nm.

## References

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