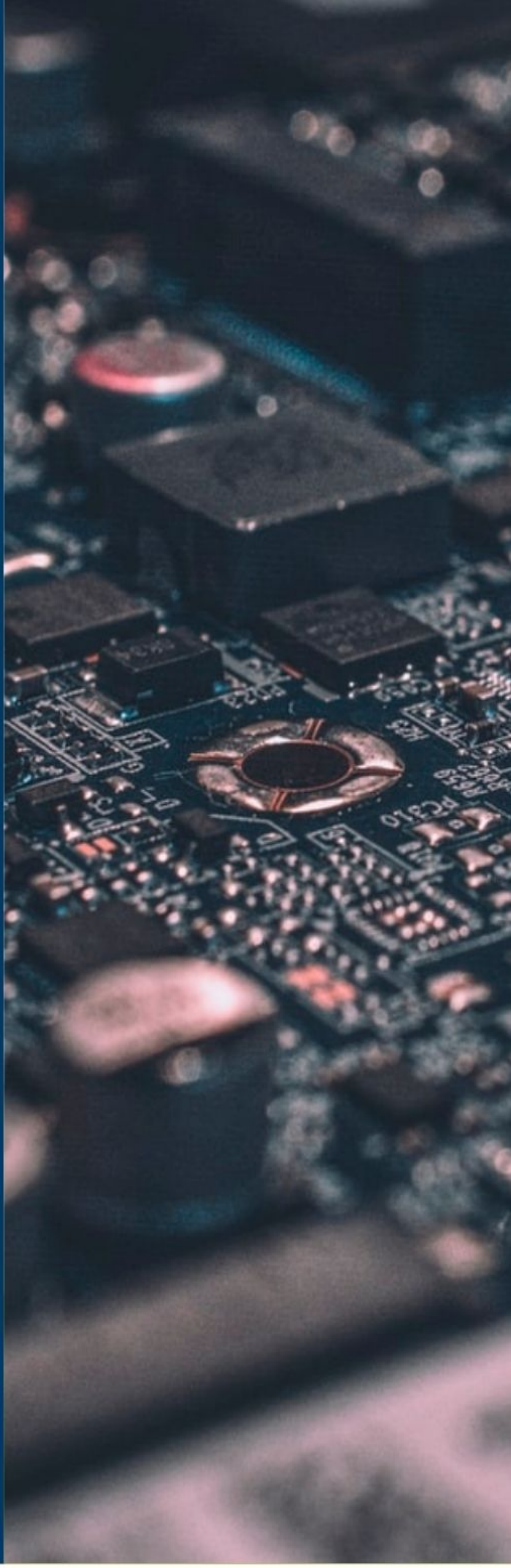

Suppression of self-pulsing in Yb fibre lasers coupled with external Fabry-Pérot cavity

J.S. Lee and J.W. Kim

A simple technique to suppress self-pulsing behaviour in a fibre laser employing a two-mirror Fabry-Pérot external feedback cavity is reported. Feedback provided by the external Fabry-Pérot cavity enforces the fibre laser to oscillate in the selected longitudinal modes, resulting in robust laser operation without self-pulsing. This technique has been successfully applied to a double-clad Yb fibre laser, yielding a stable continuous-wave output of up to 9.8 W at 1050 nm. The advantages of this technique and the prospects of further improvement are discussed.

Introduction: Fibre lasers are used in a number of application areas owing to their excellent laser performance, including power scaling capability over a kilowatt level, high wall-plug efficiency, waveguide characteristics, broad gain line widths and all fibrised configuration [1]. However, it is not so simple to achieve stable continuous-wave (CW) operation of the fibre laser since the self-pulsing phenomenon, irregular spiking behaviour in the laser output [2–5], not only induces severe output power instabilities, but can also cause catastrophic damage to the fibre itself. It is known that the self-pulsing is caused by several mechanisms such as sustained relaxation oscillation, self-modelocking due to the saturable absorption in an unsaturated part of the fibre and the nonlinear processes [3–5]. Without doubt, much effort has been devoted to suppress it and various techniques have been suggested, for example, a ring cavity fibre laser configuration [3], using a short-length active fibre in the bidirectional pumping configuration [4], resonant pumping near the lasing wavelength [6] and adding a kilometre-length passive fibre to an active fibre [7]. However, most of them have suffered from complexity, high loss and increase of nonlinearity and cost. In this Letter, we report a new and simple technique to suppress self-pulsing for achieving a stable CW fibre laser output by employing a two-mirror Fabry-Pérot (FP) external feedback cavity. This technique is successfully applied to the Yb fibre laser, yielding a robust laser operation of up to 9.8 W of the CW output without self-pulsing.

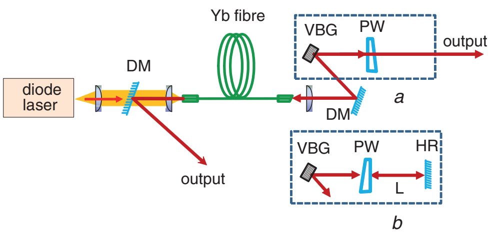

Fig. 1 *Schematic diagram of Yb fibre laser*

a Without FP external feedback cavity
b With FP external feedback cavity
PW: plane window; DM: dichroic mirror; HR: high reflection mirror

Experiments and results: The Yb double-clad fibre laser configurations used in our experiment are shown in Fig. 1. The Yb fibre had a Yb-doped core with a 10 µm diameter and a 0.08 NA surrounded by a PANDA inner-cladding with a 125 µm diameter and a >0.46 NA (LIEKKI YB1200–10/125DC-PM). Pump power was provided by a high-power fibre-coupled diode laser at ~976 nm. The absorption coefficient for a pump light at 976 nm was ~6.9 dB/m, and hence a fibre length of ~3 m was used for our experiments. A pump light was launched into one end of the fibre with the aid of a lens combination and a dichroic mirror (DM) with high reflectivity (HR) (>99.5%) at the lasing wavelength (~1050 nm) and high transmission (>95%) at the pump wavelength (~976 nm) was placed before the focusing lens to allow extraction of the Yb laser output beam. With this pumping arrangement, the launching efficiency into the inner-cladding of the fibre was measured to be ~90%. Before suppressing the self-pulsing, we first constructed the typical Yb fibre laser with a simple wavelength-tunable external cavity, as shown in Fig. 1*a*. The external cavity was composed of an aspheric collimating lens with a 6.24 mm focal length, a volume Bragg grating (VBG) and an uncoated fused silica plane window (PW). The VBG had a peak reflectivity of 95% at 1070 nm and a full-width at half-maximum reflection bandwidth of 0.3 nm. Feedback for lasing was provided by the Fresnel reflection from a perpendicularly cleaved facet at the pumping end of the fibre and one surface of the wedged PW in the external cavity. The operating wavelength was selected by tilting the angle of the VBG. The fibre end facet adjacent to the external cavity was angle polished at ~10° to suppress broadband feedback.

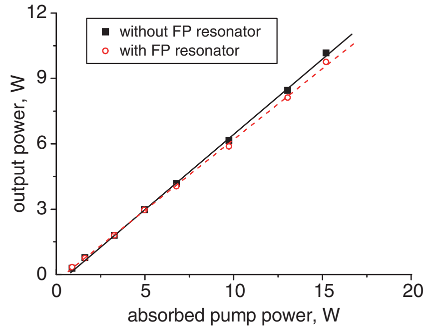

Fig. 2 *Yb laser output power against absorbed pump power*

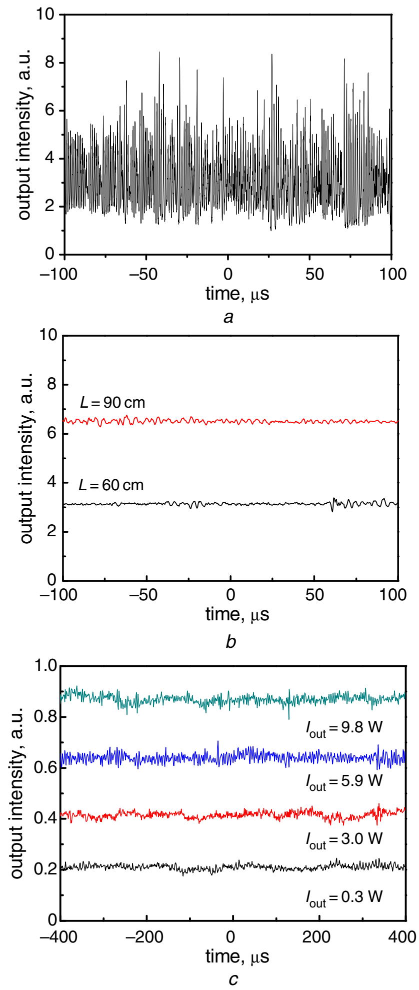

Fig. 3 *Short-term laser power stabilities for Yb fibre laser at 2.9 W*

a Without FP external feedback cavity (Fig. 1*a*)
b With FP external feedback cavity (Fig. 1*b*)
c Short-term power stabilities at different output power levels for output-stabilised fibre laser configuration (Fig. 1*b*)

Under this configuration, the output was emitted from both ends of the Yb fibre, yielding a combined output power of 10.2 W at 1050 nm for an absorbed pump power of 15.2 W, which is shown in Fig. 2 (black square). The slope efficiency with respect to the absorbed pump power was ~68% and the beam propagation factor (M^2) was measured to be ~1.03. Fig. 3*a* shows the output stability monitored with the aid of a silicon photodetector (Thorlabs, DET10A, 1 ns rise time) and the oscilloscope and the result clearly shows the typical spiking behaviour due to self-pulsing.

To suppress self-pulsing, we placed an additional HR plane mirror after the uncoated PW, as seen in Fig. 1*b*, and adjusted the HR mirror to be parallel to one of the surfaces of the PW. The result is that the PW and the HR mirror form a FP resonator providing the feedback signal for the Yb fibre laser. For the length (L) of the FP external cavity over ∼50 cm, it was found that the spiking behaviour in the output completely disappeared, as shown in Fig. 3*b*. The short-term root-mean-square power stabilities for 1 ms were measured to be <2.7% for this new configuration, which is much smaller than the plane-window-only external cavity. The long-term stability was also monitored and confirmed that the stable output was maintained over 30 min. We achieved the similar stable output behaviour without self-pulsing after replacing the VBG with the broadband high-reflection mirror at 1 μm proving that this effect was entirely due to the presence of the FP external feedback cavity. We attributed this suppression of self-pulsation to the forced longitudinal-mode operation by the FP external feedback cavity. That is, the stable longitudinal-mode oscillation locked to the FP resonator leads to rapid damping of the relaxation oscillation, resulting in the robust CW laser output without self-pulsing [8]. The detailed investigation on this mechanism is an ongoing subject.

The output power against absorbed pump power under this configuration is shown in Fig. 2 (red circle). The Yb fibre laser produced a maximum output power of 9.8 W at 1050 nm for an absorbed pump power of 15.2 W, corresponding to a slope efficiency of 65%. The beam quality (M^2) was also measured to be ∼1.03, confirming that this new laser configuration did not degrade the laser performance. Fig. 3*c* shows the power stabilities monitored at different output power levels, showing that the stable laser operation was maintained regardless of the output power levels. Furthermore, there was no evidence of the nonlinear optical effects such as SBS or SRS in our experiment. Compared with previous reports [3–7], this configuration does not show any notable degradation of laser performance even though it has a simple structure without a high-cost optical component. Furthermore, it may give another insight into the origin of self-pulsing, which is under investigation, since no similar configuration or mechanism has been reported yet. We believe that an all fibrised configuration is also possible with an optimised combination of fibre Bragg gratings for the external FP feedback cavity.

Conclusion: We have demonstrated a novel technique for stable CW Yb fibre laser operation without self-pulsing by employing the simple FP external feedback cavity. The combination of simplicity and power scalability afforded by this technique should help to construct a high-power fibre laser system with high efficiency and high stability in CW and quasi-CW mode of operation.

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One or more of the Figures in this Letter are available in colour online.

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