Enhanced pump absorption in double-clad fibres using localised laser-machined mode scramblers

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In cladding-pumped fibre lasers efficient absorption of pump light in a short length of fibre is an important requirement for scaling output power. From an integration point of view, double-clad fibres with a circular geometry are desirable, but suffer from the shortcoming that pump absorption is generally rather poor due to poor spatial overlap of some cladding modes with the doped core. To remedy this problem, it has been standard practice to use a non-circular inner-cladding (e.g. D-shaped or octagonal) to promote coupling between cladding modes and improve pump absorption. However, shaped fibres are more difficult to cleave and splice to circular fibres for integration, especially when attempting to preserve single-mode operation in large mode-area fibres.

Here we report on an alternative strategy for increasing the pump absorption efficiency with circular double-clad fibres to a level that is comparable with that achieved in octagonal fibre with the same rare-earth ion doping concentration and cladding-to-core area ratio. Our approach employs a carbon dioxide laser to laser-machine localised pump mode scramblers separated by roughly equal distances along the active fibre. In preliminary trials this approach was tested with a double-clad Tm-doped silica fibre with a 200 µm diameter circular inner-cladding and a core diameter of 10 µm. The fibre was coated with a low index polymer outer-cladding for pump guidance. The latter was removed at over short sections along the fibre separated by ~20 – 30 cm and a D-shaped cross-section was then machined using the CO_2 laser in the central region of each stripped section to provide the desired level of mode scrambling. Figs. 1(a) and (b) show the machined section of the fibre and a typical fibre cross-section at the centre of the mode scrambler, respectively.

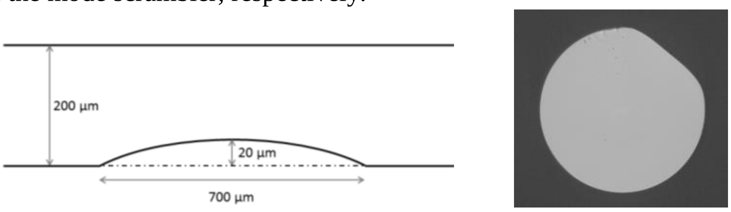

Fig. 1 : (a) Longitudinal and (b) transverse cross-section of laser machined mode scrambler.

Fig. 2(a) shows the set-up used to evaluate the absorption efficiency and pump guide propagation loss for the double-clad Tm fibre. Pump light from a fibre-coupled laser diode at 793 nm together with probe light from a diode laser at 975 nm were coupled into the Tm fibre with the aid of a 2+1:1 fibre combiner and the propagation loss at 975 nm and pump absorption efficiency at 793 nm were determined via a cut-back measurement.

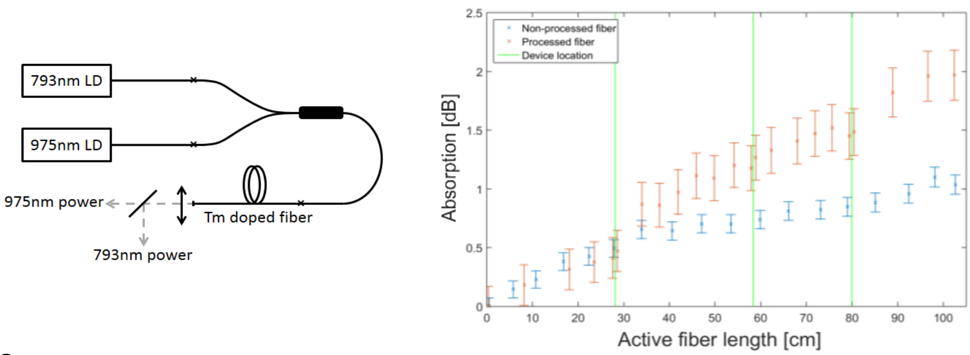

Fig. 2: (a) Experimental set-up and (b) pump absorption versus fibre length for processed and unprocessed Tm fibres

Fig. 2(b) shows pump power absorbed as a function of fibre length for the unprocessed circular fibre and the processed fibre with three mode scramblers. The results take into account the propagation loss (i.e. not due to Tm absorption) which was negligible for the unprocessed fibre and <0.1 dB per mode scrambler for the processed fibre. The pump absorption for the unprocessed fibre was measured to be ~1 dB/m, whereas the processed fibre had a much higher absorption coefficient of ~2 dB/m, which is close to the value of ~2.5 dB/m expected for a comparable octagonal fibre. Further improvements in the design of the mode scramblers to further enhance mode-coupling and reduce unwanted loss should be possible and may ultimately yield improved performance over octagonal fibres whilst at the same time facilitating integration of active fibres into more complex systems for high power single-mode operation.