Absorption measurement effects in fibres with multimode cores

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Absorption is a key characteristic of any laser medium and is often the first thing to measure. While this is rather straightforward, several factors can impair the accuracy, e.g., a non-negligible fraction of excited laser ions, nonlinear conversion, and, in multimode structures, differences in absorption between different modes. In multimode structures, mode-coupling is also important. We have previously investigated another error mechanism which had not yet been considered, namely re-emission of radiation into the absorption band of three-level systems [1]. We found that it can induce significant errors in single-mode fibres. Here, we extend those investigations to simulations of Yb-doped fibres with multimode step-index cores, focusing on the case of negligible mode-coupling. As before [1], we use a standard fibre amplifier model as implemented in RP Fiber Power to simulate white-light absorption measurements. Previously, with a single-mode Er-doped fibre, we found that this approach led to excellent agreement with measured data even for the difficult case of high absorption (up to 60 dB, with errors approaching 50%).

Figure 1 shows simulated absorption spectra. These are selected from a large number of examples and illustrate only a fraction of interesting effects. The steps in the spectra are due to limitations in the spectral resolution imposed to allow for simulations of large number of modes (those simulations are not shown here).

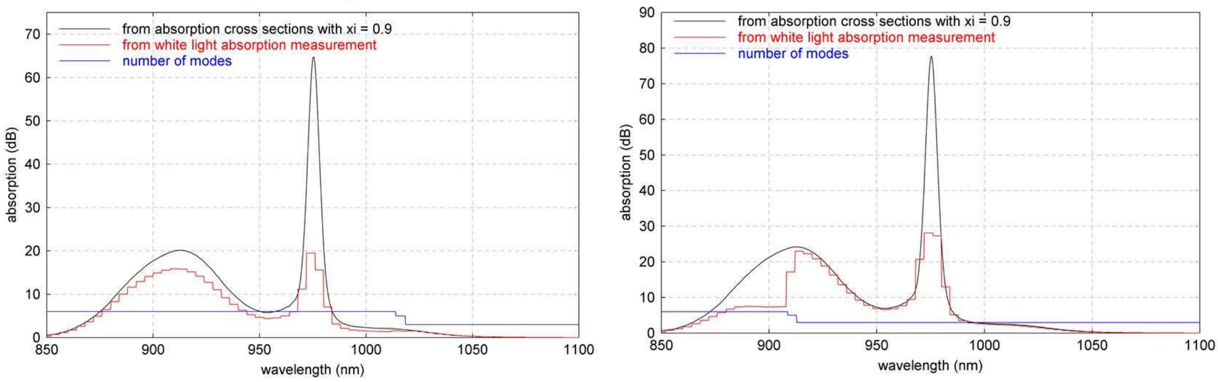

Fig. 1 Simulated white-light absorption spectra of multimode Yb-doped fibres with different cut-off characteristics. Black curve: Ideal (“error-free”) absorption spectrum with overlap 0.9. Red curve: Simulated white-light absorption spectrum. Blue curve: Number of guided modes.

As for the single-mode case [1], we found that the numerical aperture can play an important role, since a large NA allows for a larger fraction of re-emitted photons to be captured. However it is the effect of the cut-off wavelength which is most striking. The left graph in Fig. 1 is for a case without any cut-off in the high-absorbing regions of the spectrum. Still, the absorption peak is severely distorted. Like fore the single-mode case [1], this is an effect of re-emission. The right figure, with cut-off around 910 nm, is quite different with a strong step in the simulated absorption near the cut-off. While the increase of the number of modes automatically leads to an increase in the received power, and thus a decrease in the measured absorption, the step is much larger than the change in the number of modes. The reason for this is the low overlap between the doped and the mode near cut-off.

Our simulations beg the question why such behaviour is generally not seen in measurements. We believe the reason is mode-coupling and high micro-bending loss of modes with very low overlap with the core. Nevertheless, we expect that small high-NA multimode cores, which are still relatively frequently encountered, can exhibit this behaviour. Small cores lead to less mode-coupling, and should also allow for low-loss propagation even when a large fraction of the power is in the evanescent field outside the core. Experiments on this will be presented at the conference.

References

[1] Betty Meng Zhang *et al*., “Fiber absorption measurement errors resulting from re-emission of radiation”, in Advanced Solid State Lasers, OSA Technical Digest (online) (Optical Society of America, 2015), paper AM5A.20