Investigation into Yb-doped fibre amplifiers as pre-amplifiers for Vulcan

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Introduction

In recent years fibre lasers and amplifiers have become a popular and successful technology as they offer the potential for high gains over relatively large bandwidths. In this report we present the findings of an investigation into the potential of Ytterbium-doped fibres as pre-amplifiers for Vulcan. The fluorescence of the fibre was investigated at low pump powers revealing ASE between 1.0-1.1 µm whose peak shifted from lower to higher wavelengths as the length of fibre increased. Higher pump powers gave lasing effects between 1040-1070 nm with the lasing wavelength also increasing with length. Gain has not yet been achieved at 1053 nm, the required wavelength for Vulcan but computer simulations predict that it is achievable at higher pump powers.

Theory

Fibre amplifiers use rare earth metal doped fibre cores as gain media, pumped by diode lasers either directly into the core of a single mode fibre, or the inner cladding of a double clad fibre. The use of double clad fibres relaxes the brightness requirement of the pump diodes and enables higher power devices to be used. Yb was chosen as it emits between 1.0-1.1 µm however it is a quasi-three level laser system with significant thermal populations in the lower laser level. This population in the lower laser level can lead to re-absorption losses and this has implications for the design of amplifiers as will be highlighted. It has a large absorption coefficient at 976 nm and so the fibre was pumped with this wavelength. Its lasing levels are very close together and it has a broad ASE bandwidth. The ASE and gain in the fibre at 1053 nm was modeled and reported on in [1].

Initial low pump power tests

Figure 1 shows the schamtic of the experimental set-up for the initial investigation of the fibres. The fibre investigated was a double-clad fibre with 5.5 µm single-mode Yb-doped core and multimode 125 µm inner cladding. The NA in the core is 0.1 and that of the inner cladding is ~0.4. A 1053 nm CW seed laser was coupled into the Yb doped fibre by reflecting the beam off a mirror coated to be HR @ 1053 nm and AR @ 976 nm. The pump was coupled into a passive fibre to match the divergence of the pump beam in the two orthogonal directions this passive fibre had a 200 µm diameter core and a NA of 0.2. A telescope was then used to match the beam radius as closely as possible to the inner-cladding diameter reducing the pump beam to match that of the active fibre and yet maintaining a suitable NA. A total CW power of 250 mW was available for injection into the active fibre.As can be seen the seed and pump beams then counter-propagate through the inner-cladding of the fibre, the inner cladding is designed so that it is slightly asymmetric so that the cladding mode overlaps with the core mode and the pump is then transferred into the pump where it is absorbed.

Fluorescence measurements

The fluorescence of the Yb fibre was investigated by pumping with a 1 W 976 nm diode for these tests the seed laser was replaced with a collection fibre for an Ocean Optics spectrometer. The output spectrum for a 1 m long lenth of fibre is shown in figure 2 (left). As can be seen the spectrum has a peak at the pump wavelength due to unabsorbed pump and amplified spontaneous emission, ASE, at wavelengths between 1000 nm and 1060 nm. The peak wavelength of the

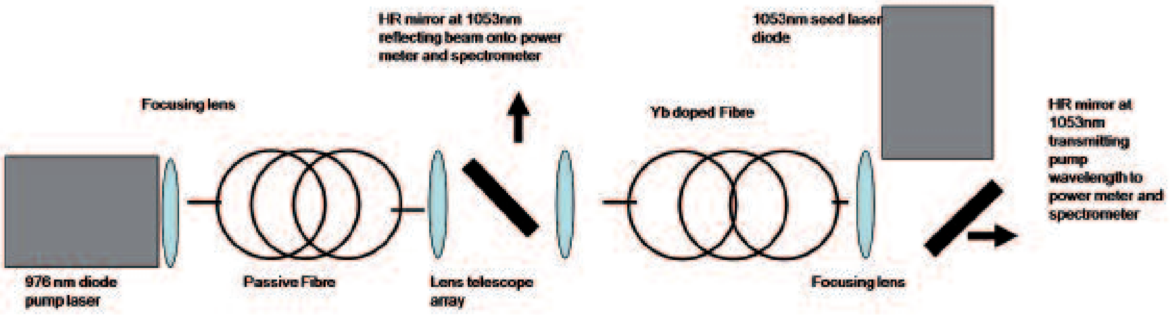

Figure 1. Schematic of Amplifier.

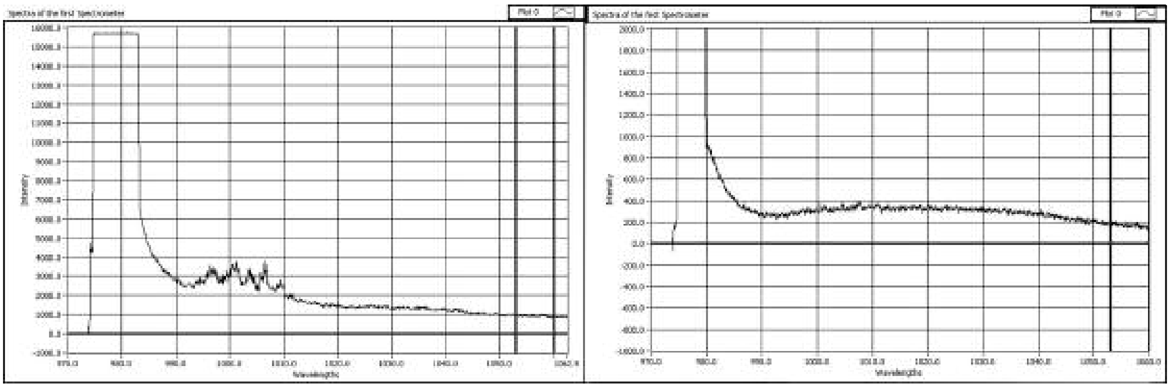

Figure 2. The ASE spectral shift. The spectrum on the left is a 160 mm fibre with an ASE peak at 1000 nm whereas the spectrum on the right shows a 2 m fibre with an ASE peak at 1020 nm. This agreed with the model.

ASE spectrum was dependent on the length of the fibre: shorter fibre lengths, less than 1 m, had peaks at 1000 nm with a band of ASE between 990 nm and 1010 nm but as the length of the fibre was increased above 1 m, the ASE spectrum became much broader and two peaks started to appear, one at 1000 nm and one at 1020 nm. After 2 m the ASE band stretched from 1000 nm to 1060 nm with a peak at 1020 nm as shown in figure 2 right, this increased to 1030 nm for longer fibre lengths. The shift in the spectrum is attributed to reabsorption the longer the wavelength the lower the absorption coefficient. Consequently for the shorter lengths of fibre there is higher gain for the shorter wavelengths and the short length means that there is little reabsorption however as the fibre length is increased reabsorption begins to take place and the longer wavelengths begin to experience greater effective gain than the shorter wavelengths..

High pump powers

The model showed that pump power is critical for achieving gain this is because the reabsorption losses must be overcome for there to be gain. Even with small seed input, high gains could be achieved with large pump input. The model predicted that the pump power available from the 1 W diode was insufficient to overcome these losses. Consequently higher pump powers were investigated by coupling a 20 W diode into the fibre.

Figure 3 shows some interesting fluorescence results from the 6 m fibre showing that the fibre is lasing at a wavelength of ~1070 nm. During the measuring of the wavelength it was observed that the lasing wavelength scanned from 1060 nm to 1070 nm with it taking several seconds to scan between the wavelengths. This behavior was self-starting and stable for several minutes of observation. This effect could not be replicated when the fibre was moved to a different mount without the final collimating lens and so the most likely explanation is that there were back-reflections from the lens by the coating on the focusing lens: it is coated to be anti-reflective at 1053 nm and so will have a reflective component at other wavelengths. Although this explains the reason for the lasing it does not explain the observed scanning effect. When the lens replaced the scanning was observed again however it was less stable and tended to jump between wavelengths rather than smoothly scan.

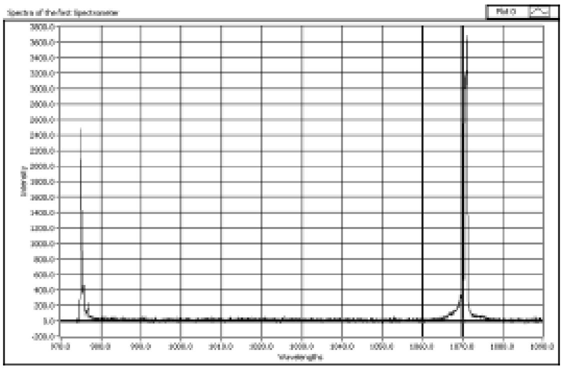

Figure 3. The frequency scanning laser with its wavelength limits marked.

Even without the lens, the 6 m fibre showed lasing around 1060-1070 nm. Figure 4 shows the integrated output power of the laser against the current of the pump diode for the 6 m long fibre. As can be seen there is a threshold current at ~6 A this equates to approximately 1 W of pump power. In comparison A 4 m length of fibre was also tested. This showed the expected spectral shift to a shorter wavelength than the 6 m fibre, lasing between 1040 nm and 1060 nm. This lasing will take power away from amplifying the signal and will need to be overcome to achieve gain.

A laser cavity was created by placing a broadband mirror at the end of the 4 m fibre. This lased between

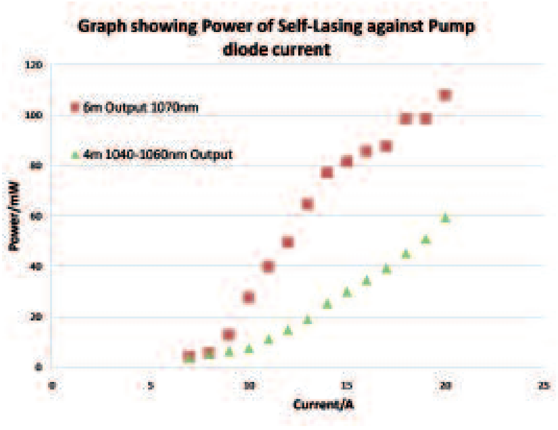

Figure 4. Graph of the power of the self lasing for the 4 m and 6 m fibre.

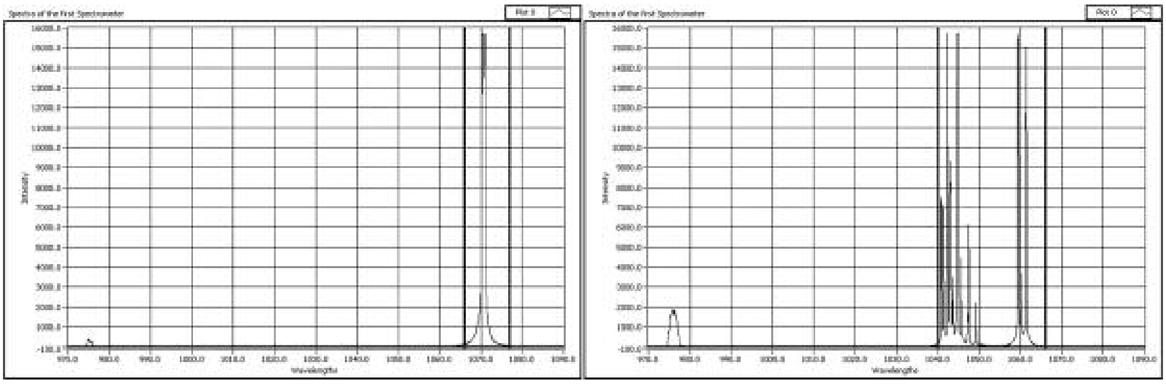

Figure 5. Lasing at 1070 nm for a 6 m fibre, left, and lasing between 1040-1060 nm for a 4 m fibre, right.

1040-1070 nm at a power of 450 mW at 20 W of pump power. It was noted that for higher pump powers lasing had a higher intensity at the longer wavelengths and for lower pump powers ASE around 1040 nm was more dominant due to the reabsorption of the shorter wavelengths

Conclusion

The ASE and lasing in the fibre showed a spectral dependence on fibre length due to reabsorption of shorter wavelengths in the core. This dependence will be important in choosing the length of the fibre for the amplifier. There was ASE shown at 1053 nm, which shows that gains at this wavelength could be achievable; these are predicted for high pumping powers. The fibre had a very broad bandwidth and showed high powers of self-lasing along these wavelengths; this could be utilised to investigate the bandwidth in the rod chains in Vulcan.

Further work

High gains are predicted for coupling with the 20 W diode pump and the ASE indicates that gain at 1053 nm, Vulcan's wavelength is achievable. Work will continue in finding a more efficient method for launching the seed into the core, potentially by using a WDM combiner. Lower dopant concentration fibres will be investigated to reduce some of the reabsorption losses.

References

1. P. Anderson, *'Numerical simulations of Yb-doped fibre amplifiers utilising small scale parallelism'*, CLF Annual Report 2008-2009.