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Progress in the Development of Efficient 1.3μm Fibre Amplifiers

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Abstract: Progress in the development of the elusive pump-efficient 1.3μm optical fibre amplifier is reviewed. Four possibilities exist, all in non-silica glass. At present, there is no clear winning technology, but the availability of high-power pump diodes could favour the more conventional approaches.

The telecommunications industry is currently undergoing a rapid transformation towards all-optical systems and networks. The upgrade to all-optical operation is well advanced in the long-haul 1.5μm networks which take advantage of the highly successful Er^{3+}-doped optical fibre amplifier (EDFA) introduced in 1987.[1] The result is a global optical amplifier market expected to be worth nearly £1 billion pa by 2004, despite the fact that EDFAs are not appropriate for operation at the 1.3μm zero-dispersion window that dominates existing terrestrial fibre systems. An optical amplifier at 1.3μm is required to upgrade presently installed optical links and to promote a balanced evolution of the optical network and to support the expected traffic requirements needed for interactive video and multimedia services. It is worth noting that with development in optical fibre manufacturing, there is now a need for amplifiers spanning the full tranmission window from 1.2μm - 1.7μm.

The research in fibre amplifiers at 1.3μm encompasses study of active ions with suitable transitions like rare-earth ions Pr^{3+}, Dy^{3+} and Nd^{3+} in different host glasses such as in fluorides, chlorides and chalcogenides.

The first generation of 1.3μm praseodymium-doped fluoride fibre amplifiers (PDFFAs) based on Pr^{3+}-doped ZBLAN is already available on the market. It is characterised by a gain peak at 1300nm and 3dB bandwidth of 25-40nm depending on input power.[2] The ground state absorption (GSA) to the metastable state is broad, 950-1060nm with line centre at 1010nm, allowing use of different pump wavelengths. However, the absorption is weak and a PDFFA fibre is normally at least 10 metres long. The PDFFA's biggest limitation is in pump efficiency owing to a high nonradiative decay rate from the metastable to an intermediate level which dominates the 1.3μm emission. A 30dB gain amplifier requires 300mW pump power around 1017nm. This cannot be easily achieved with a single semiconductor pump laser. For this reason, PDFFA devices have been pumped by expensive Nd:YLF lasers at 1047nm, away from the peak absorption wavelength, and the pump requirement is further increased to 600mW levels.[3] The development of sufficiently intense semiconductor lasers for peak absorption LD pumping of PDFFAs will encourage the realisation of the second generation of such amplifiers based on lower phonon energy glasses than ZBLAN, such as Pb-Ga-In (PGI) fluoride glass, with thermal stability against crystallisation and a fibre loss similar to stable ZrF$_4$-based glasses.[4]

The amplifier pump efficiency improves dramatically when the quantum efficiency is increased by placing Pr^{3+} in very-low phonon-energy glass to reduce multiphonon quenching. Sulphide-based chalcogenide glasses have phonon energies of ~400cm^{-1} cf 580cm^{-1} in ZBLAN, the radiative quantum efficiency can be greater than 50% (c.f. ~4% in ZBLAN, ~7% in PGI). Gain measurement results using Ga-Na-S fibre report a peak net gain at 1.34µm and a gain coefficient (bi-directional pumping configuration) of 0.81dB/mW, compared to the best PGI fluoride fibre of 0.36dB/mW. The amplifier is thus able to deliver 30dB net gain with less than 100mW of 1017nm pump power.[5] However, the biggest drawback is that the gain peak is red-shifted in a sulphide host to about 1.34μm, so that the gain is well down at 1310nm, the preferred operating wavelength.

Dysprosium in low phonon energy glasses such as sulphides and chlorides has a suitable transition at 1.3µm.[6,7] The emission is centered at 1310nm with FWHM of 40nm and the quantum efficiency is expected to be around 70%. However, Dy^{3+} exhibits a significant GSA, which must be bleached in order to achieve net gain, i.e., it behaves like a 3-level amplifier. To date, no fibre gain measurements have been reported.

Nd^{3+} is another active dopant. Novel glass design has resulted in a glass composition based on AlF_3 such that the gain peak is inside the second telecom window at 1310nm (near the zero-dispersion region of silica at 1317nm). It is a four-level system and the transition from the metastable level is purely radiative. In order to achieve a high gain amplifier, the competing 1050nm amplified-stimulated-emission must be filtered out. The use of gratings is one possible means of achieving the desired filter characteristics. In Nd^{3+}-doped AlF_3-glass fibre, there is the potential for an efficient and inexpensive optical amplifier able to deliver 30dB gain using <100mW pump power in a single pass.[8] It has a convenient pump wavelength at 800nm where inexpensive laser diodes are commercially available. The strong absorption of Nd^{3+} at 800nm and the high solubility of the ion in the glass gives a short device.

Conclusion

Although there are four candidate fibres for 1.3μm doped fibre amplifiers (Pr^{3+} in ZBLAN, PGI or sulphide, Nd^{3+} in AlF) each has disadvantages compared to the EDFA operating at 1.53μm. Many of these disadvantages are fundamental and lead to an amplifier which is expensive, or has compromised performance. The commercial development which can change this is the availability of high-power pump sources which would ease the current preoccupation with pump efficiency.

References

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