A 1300nm Nd^{3+}-Doped Glass Amplifier

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Abstract

In terms of its optimised performnance, superior small signal gain and lower noise figure, a Nd^{3+}-doped device will out perform a Pr^{3+}-doped device in any glass host in terms of an amplifier operating at >1310nm, the operating wavelength region for much of the currently installed fibre base.

Introduction

In Nd^{3+}-doped glasses, a strong signal excited-state-absorption (ESA) process severely reduces the efficiency of the 1300nm stimulated emission and shifts the gain peak to longer wavelength such that the overlap with the telecom window becomes relatively poor [1]. Using the results of absorption measurements coupled with a Judd-Ofelt analysis, a criterion to determine the best possible glass composition has been established. The JO-analysis returns the parameters Ω_2, Ω_4 and Ω_6 . An examination of the tensor operators defining the relevant transitions reveals that the 1300nm emission is dependent only on U_6, while the 1300nm ESA depends only on U_2 and U_4. Thus the ideal glass will have minimum values for Ω_2, Ω_4 and maximum values for Ω_6. Ω_2 and Ω_6 are strongly glass host dependent, where Ω_2 decreases with increasing ionicity of the glass and Ω_6 increases when the rigidity of the glass matrix decreases. A novel family of non-toxic fluoroaluminate (AlF) glasses have been identified as the most promising host for a Nd^{3+}-doped glass amplifier .

In Nd^{3+}-doped AlF, we have the potential for an efficent and inexpensive amplifier. It has a convenient pump wavelength at 800nm where inexpensive laser diodes are commercially available unlike the 1015nm required in Pr^{3+}-doped devices. The strong absorption of Nd^{3+} at 800nm (170dB/m/1000ppm) and the strong solubility of the ion in AlF glass (upto $4x10^4$ ppm) suggest a short device of ~2cm unlike the 10m needed in Pr^{3+}-doped amplifiers.

Results

Sample AlF glass compositions are given in Table 1. For AlF glasses, the more ionic the glass the smaller the refractive index, n_D. Table 2 gives the measured peak emission wavelength, λ_p, the JO-parameters derived from measured absorption data and the calculated emission and esa cross-section ratios, A_{em}/A_{esa},. The results are compared with commercially available glasses. All glasses are doped with 1mole% NdF_3. Ionic glasses have blue-shifted λ_p and strongly ionic AlF glasses have smaller Ω_2 and larger A_{em}/A_{esa}. AlF123 has an Ω_2 almost half- and A_{em}/A_{esa} almost 1.7 times that of ZBLAN.

A fibre using AlF70 has been fabricated with a numerical aperture (NA) of 0.23, core diameter of 8μm and loss at 1300nm of ~100dB/m. Three-centimeter lengths of the fibre were mounted inside a capillary and both end faces polished. The fibre was then pumped by a Ti:sapphire laser operating around 800nm. In order to minimise any

Table 1

Sample	Composition (mole %)	n_D
AlF 70	$37AlF_3$:$12MgF_2$:$15CaF_2$:$9SrF_2$:6BaF2:14YF_3, $6NaPO_3$	1.432
AlF117	$39AlF_3$:$7MgF_2$:$30CaF_2$:$7SrF_2$:7BaF2: 9LiF	1.402
AlF123	$39AlF_3$:$6MgF_2$:$22CaF_2$:$6SrF_2$:6BaF2: 10LiF:10NaF	1.397
LG810	commercial fluorophosphate	1.453
ZBLAN	commercial ZrF_4-based fluoride	1.541

Table 2

Sample	λ_p (nm)	Ω_2	Ω_4	Ω_6	A_{em}/A_e	λ_{laser} (nm)
AlF 70	1317	1.44	2.95	4.06	2.40	1317
AlF117	1317	1.00	4.01	5.36	2.97	
AlF123	1317	1.15	3.39	5.83	3.48	
LG810	1320	2.65	3.22	5.06	2.08	1323
ZBLAN	1317	2.2	2.83	3.94	2.01	1330

thermal problem associated with the high pump powers (>300mW), the pump laser was chopped with a low mark/space ratio (1:10). The fibre lased at the peak of the 1049nm emission curve, a result similar to that obtained in Nd^{3+}-doped ZBLAN fibre. Significantly, this result implies at least 15 dB of net gain. (the laser utilises the 3.5% Fresnel reflection from the fibre end faces). The branching ratio between the 1049nm emission and the 1317nm emission is 5:1, thus at least 3 dB of net gain in the 1317nm region of the spectrum is expected.

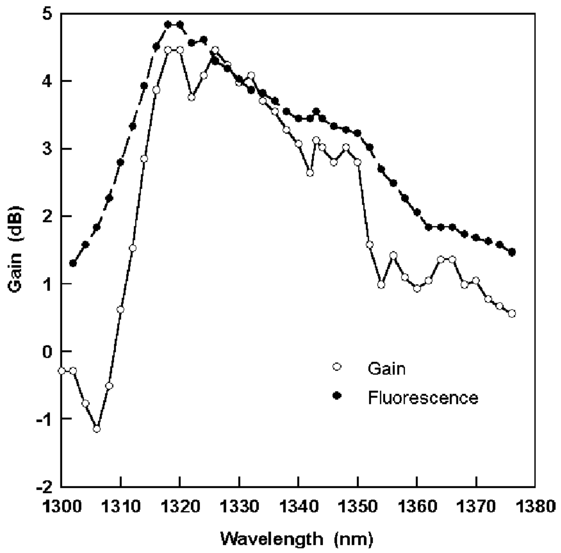

Figure 1: Gain of Nd^{3+}-doped AlF fibre.

For measuring the gain spectrum of the Nd^{3+}-doped AlF fibres, a 1300nm LED signal source was used and chopped at ~300Hz. This allows a lock-in amplifier to be used in the detection system and allows discrimination between the signal and any ASE/fluorescence. The gain is then simply the ratio of the measured signal with the pump and off. The end face of the fibre was angle polished at ~15^0 in order to suppress the lasing at 1049nm. The gain from 1280nm to 1380nm was measured for a 3 cm length of fibre. The measured gain spectrum is shown in Figure 1 and is compared with the measured fluorescence spectrum for the same Nd^{3+}-doped fibre. Significantly, the two spectra have very similar peak wavelengths, indicating that negligible ESA occurs at this wavelength. The peak wavelength at 1317nm corresponds to the wavelength of zero dispersion in UK installed fibres. At shorter wavelengths, the gain spectrum falls off more quickly than the fluorescence, indicating that significant amounts of ESA are present in this region of the spectrum.

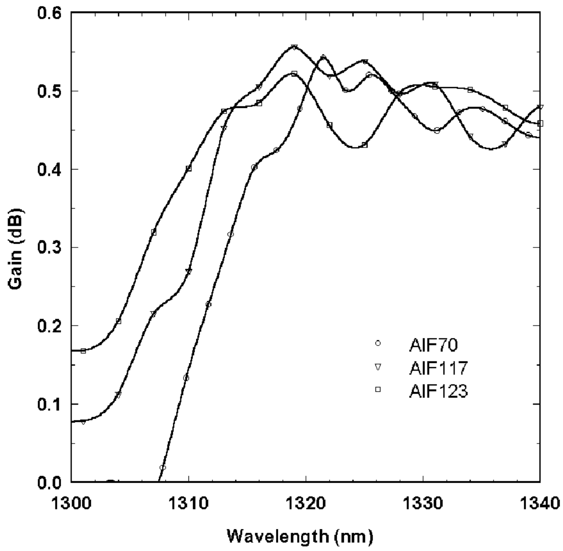

Figure 2: Gain measurements of Nd^{3+}-doped AlF.

The laser emission spectrum for this fibre occurs at at the peak of the gain curve at 1317nm. This was measured by butting two high reflecting mirrors (reflectivity >80% at wavelengths between 1200-1400nm and <10% between 900-1100nm) to both of the fibre ends. This lasing wavelength is significantly shorter than that achieved in either fluorophosphate [2] or fluorozirconate [3] fibres as compared in Table 2, again indicative of reduced ESA.

The fibre used in these measurements is not ideal for amplifier measurements. The cut-off wavelength is ~2.4μm and consequently the fibre is highly multimode at the 1300nm signal wavelength. Furthermore, we have measured the lifetime in the fibre at low pump power to be ~450μs decreasing to about 250μs at higher pump powers (but still well below the power required for amplified spontaneous emission, ASE). These figures compare with 530μs in the bulk glass. This indicates that some quenching is present in the fibre. Further increases in device efficiency can be achieved through lower fibre losses and optimised fibre parameters. It is difficult to get low-loss singlemode fibres as the thermal cycling involved in the current fibre fabrication process promotes core-clad interface and bulk crystallisation.

In order to measure the gain profile at 1300nm, we have pulled unclad fibres of diameter between 50μm and 20μm. By pumping short lengths we can obtain a measurable level of gain as shown in Figure 2.

The gain at shorter wavelengths clearly increases with increasing glass ionic character, corresponding to an increase in A_{em}/A_{esa} . There is also evidence that the ESA transition is more blue-shifted than the emission transition in strongly ionic glasses and hence the region of ovelap is reduced in addition to the reduction in A_{esa}, altogether favouring gain at shorter wavelengths.

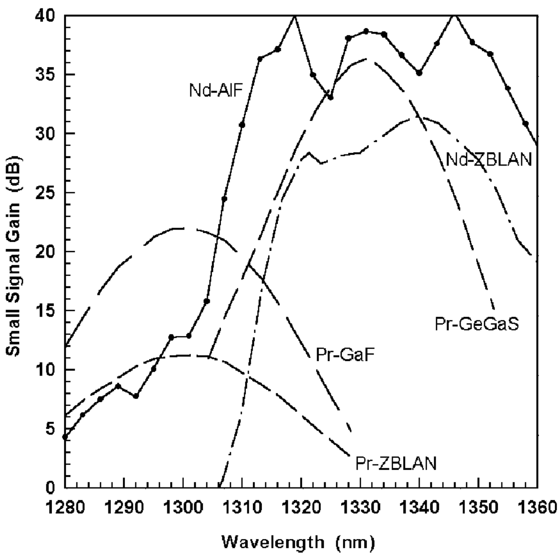

Figure 3: Comparison of Gain in Different Glasses

In Figure 3, the gain spectrum expected for a Nd^{3+}-doped AlF123 device with appropriate 1049nm ASE filtering is compared with a Nd^{3+}-doped ZBLAN [1] and a number of Pr^{3+}-doped [4,5] glass fibre gain curves. A fibre NA of 0.4, pump power of 100mW and negligible fibre loss are assumed in all cases. The pump wavelength is 1015nm for the Pr^{3+}-doped device and 800nm for the Nd^{3+}-doped amplifier.

The most promising host for a Nd^{3+}-doped amplifier is an AlF glass optimized for maximum signal to ESA ratio while maintaining the emission peak wavelength as short as possible. The measured Nd^{3+}-$^4F_{3/2}$ lifetime of around 500μs is also among the longest measured in a multicomponent glass. Thus, the small-signal gain which is directly proportional to the product of the signal/ESA ratio and lifetime is favourable.

Conclusion

The presence in all Pr^{3+}-doped fluoride devices of increasing excited- and ground-state absorptions (ESA and GSA) at wavelengths >1310nm causes a strong deterioration in the performance at such wavelengths[4]. Given that the zero dispersion wavelength in many installed fibres is >1310nm and the ESA is negligible in Nd^{3+}-doped AlF at these wavelengths, we anticipate that Nd^{3+}-doped amplifiers will provide superior performance in such links.

References

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