POLARISATION EFFECTS IN FIBRE LASERS.

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ABSTRACT

Two orthogonal polarisation eigenmodes have been observed in a single-mode fibre laser. Experimental investigation shows good agreement with theoretical analysis. Both Nd^{3+} and Er^{3+}-doped single-polarisation single-mode fibre lasers have been demonstrated.

Introduction

An understanding of the polarisation properties of fibre lasers [1-4] is important for producing single-polarisation lasers, as well as a number of sensor and switching devices. In addition, polarisation-sensitive intra-cavity components such as fibre gratings or acousto-optic modulators are frequently employed and these interact with the laser polarisation. We present here an analysis of the polarisation behaviour of fibre lasers and draw significant conclusions as to the polarisation behaviour of the gain atoms in a fibre laser. Optimum operating conditions for selective fibre laser output polarisation are given.

Theory

Even in the absence of intra-cavity polarising elements, we have observed that the output polarisation state and degree of polarisation (DOP) of a fibre laser are both strongly affected by the polarisation orientation of the pump laser, i.e. the laser output 'remembers' the polarisation state of the pump to some degree. An understanding of the phenomenon requires a knowledge of how the local gain for each state of polarisation depends on the pump polarisation, as well as how this anisotropic gain interacts with the birefringence of the fibre.

Owing to the random site-to-site variations in environment seen by the dopant ions in a glass matrix, different ions interact more strongly with different polarisation states.[5] This is true both for absorption of a polarised pump-source and the probability of stimulated emission, i.e. gain. The cross-section anisotropy of the ion sites can be described by $a=\sigma_s/\sigma_p$, where σ_p and σ_s respectively represent maximum and minimum cross-section, for each ion site [5].

In general, this anisotropic gain is orientated at an angle to the two orthogonal principal axes of the fibre birefringence, the angle depending on the pump polarisation orientation.

Using the cross-section ratio a and integrating over all possible site orientations, the DOP of the output from a fibre laser can be shown to be

$$\mathrm{DOP} = \frac{1 - 2a + a^2}{2 + 6a + 7a^2} \cdot \frac{1}{1 - (P_x + P_y)/P_o} \cdot \cos(2\alpha) \qquad (1)$$

where P_x and P_y are the pump threshold powers required for of the x- and y-mode respectively, P_o is the input pump power and α is the pump polarisation angle relative to the x principal-axis.

Experiment

A number of fibre lasers have been investigated and the results are in good agreement with the theoretical analysis described above. The experimental setup is similar to that described in previous reports [6].

Fig.1.shows power output as a function of pump power and pump polarisation orientation for a Nd^{3+}-doped fibre laser pumped by an Ar^+-ion laser operating at 514nm. The 20m-long fibre laser had a conventional design and contained 30ppm of Nd^{3+}. When the pump polarisation is aligned with the fibre principal axis (α=0) it can be seen that a considerable difference exists in the threshold and slope efficiency of the x- and y- polarised modes, thus demonstrating the predicted gain anisotropy. However, as expected, when the pump polarisation is orientated at 45° to the fibre principal axes the characteristics of the two polarised laser modes are almost identical.

A semiconductor-laser pump was used to verify the dependence of the DOP on the pump polarisation angle α . The results for a 3m length of 300ppm Nd^{3+}-doped fibre are shown in fig.2 and illustrate the close agreement with the expected $\cos(2\alpha)$ function of eqn.1. Fig.3 illustrates the variation in the DOP of the laser output with absorbed pump power. Again, this follows the form predicted by Eqn.1.

From Figs. 2 and 3 we see that far above threshold ($P_o \gg P_x, P_y$) the DOP at α=0 (i.e. on-axis pumping) reaches approximately 0.5. Substitution of this value into Eqn.1 gives a = 0, leading to the interesting conclusion that the Nd^{3+}-ions can be described by a pure aligned-dipole model.

We conclude that the optimum conditions for obtaining a polarised output from the fibre laser are:

(i) Pumping with polarisation aligned to the fibre principal axis.

(ii) Operating the laser at just below the threshold of the secondary polarisation eigenmode.

Under these conditions the DOP can be as high as 0.98, decreasing to 0.5 as the pump power is increased. [Fig.3]

In order to achieve more output power and a higher extinction ratio, increasing the difference between the thresholds of the two polarisation eigenmodes is needed. An effective method is to introduce a preferential loss by introducing a low-loss high extinction-ratio single-mode fibre polariser into the cavity of the fibre laser [6]. This technique exploits the interaction of the evanescent field of the lasing mode with a short length of metal embedded in the cladding of the fibre.

The effectiveness of the technique is shown in Table 1 which lists the extinction-ratio obtained for Nd^{3+}- and Er^{3+}-doped fibre lasers with various pump sources. An extinction ratio as high as 35dB can be obtained for a Nd^{3+}-doped fibre laser.

References

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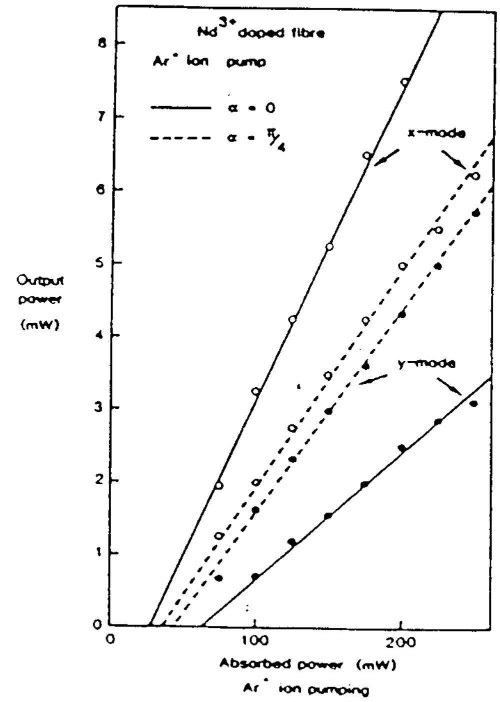
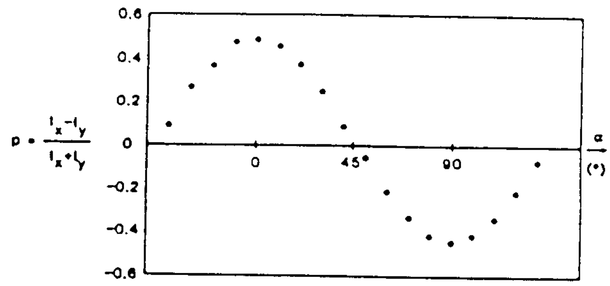
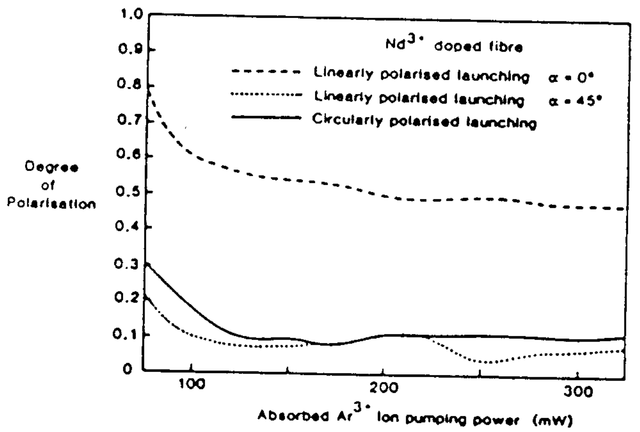


<< Fig. 1
Different lasing characteristics of the two polarisation eigen modes for two pump polarisation angles



^^ Fig. 2
Degree of polarisation versus the polarisation orientation of the launched pump light



<< Fig. 3
Degree of polarisation of laser output versus absorbed pumping power shown for various pump polarisation states

Table 1. Single polarisation operation of fibre lasers

DOPANT ION	FIBRE LENGTH	PUMP SOURCE	LASER WAVELENGTH	OUTPUT MIRROR TRANSMISSION	EXTINC. RATIO	OUTPUT POWER
Nd^{3+}	20m	Ar^{+}-ion 514nm	1088 nm	65%	35.4dB	20mW
Nd^{3+}	9m	LD 825nm	1088 nm	1%	30 dB	85μW
Er^{3+}	1.4m	Dye DCM 650nm	1536nm	20%	22dB	1.2mW