TUJ25 Modeling of polarization effects in fiber lasers

J. T. LIN, W. A. GAMBLING, D. N. PAYNE, U. Southampton, Dept. Electronics & Computer Science, Optical Fibre Group, Southampton SO9 5NH, U.K.

Experimental investigation of various fiber lasers containing rare earth ions shows that the polarization effects[1–3] with a Fabry-Perot cavity can be characterized by three basic factors: (1) The fluorescence caused by spontaneous emission is depolarized independently of the polarization of the pump light. (2) Two orthogonal phase-independent polarization eigenmodes exist in the single-mode fiber laser cavity. (3) The polarization state of the output from the fiber laser depends on the orientation of the pump light polarization, pump power level, and dopant characteristics. The evidence of polarization effects in a Nd^{3+} doped fiber laser can be clearly seen from Figs. 1 and 2 and Ref. 1.

It is now possible to postulate a model for characterizing polarization effects in fiber lasers based on these three factors. Assuming a random orientation of the electric dipole of the rare-earth ions in the fiber, the concept of an effective pump power for each of the polarization eigenmodes can be introduced and may be expressed as

$$\begin{bmatrix} P_x \\ P_y \end{bmatrix} = P_{ab} \begin{bmatrix} \cos^2\alpha & \sin^2\alpha \\ \sin^2\alpha & \cos^2\alpha \end{bmatrix} \begin{bmatrix} C_1 \\ C_2 \end{bmatrix}, \qquad (1)$$

where

$$C_1 = (3 + 4A + 8A^2/(4 + 12A + 14A^2),$$
$$C_2 = (1 + 8A + 6A^2)/(4 + 12A + 14A^2). \qquad (2)$$

In Eqs. (1) and (2), the parameter A is the polarized cross-section ratio[3] defined as $A = \sigma_s/\sigma_p$, α is the angle the pump polarization makes with the x axis, P_{ab} is the total absorbed pump power, P_x and P_y are the effective absorbed pump power components for the x and y polarization eigenmodes, respectively.

The concept of an effective absorbed pump power component presented above is now applied to existing laser theory, which is valid only for one individual lasing mode to analyze the polarization eigenmodes in a fiber laser. Thus the laser performance for each polarization mode can be predicted.

This model fits the experimental results rather well. For example, the predicted ratio of the relaxation oscillation frequencies of the x and y modes is

$$\frac{\omega_x}{\omega_y} = \sqrt{\frac{C_1 \cos^2\alpha + C_2 \sin^2\alpha - P_{th}/P_{ab}}{C_1 \sin^2\alpha + C_2 \cos^2\alpha - P_{th}/P_{ab}}}. \qquad (3)$$

Equation (3) indicates that ω_x/ω_y decreases as the pump power increases, in accordance with experiment and as illustrated for the particular case of $\alpha = 0$ in Fig. 2. Furthermore the predicted degree of polarization (DOP) also fits well with measurement, as seen in Fig. 1.

In particular, the relative slope efficiencies of the x and y modes are found to be

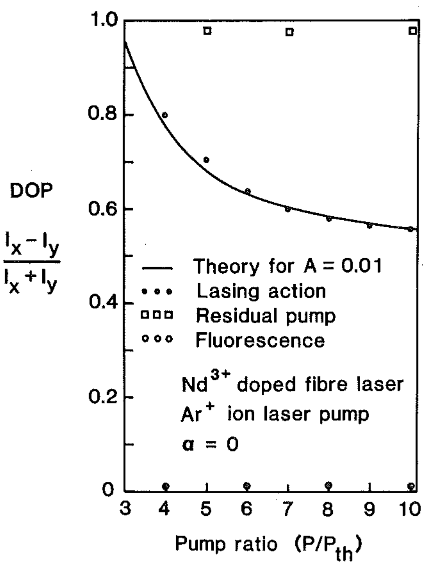
$$\frac{\text{SLOPE}_x}{\text{SLOPE}_y} = \frac{C_1 \cos^2\alpha + C_2 \sin^2\alpha}{C_1 \sin^2\alpha + C_2 \cos^2\alpha}. \qquad (4)$$

which again fits well with experimental measurements (Fig. 3).

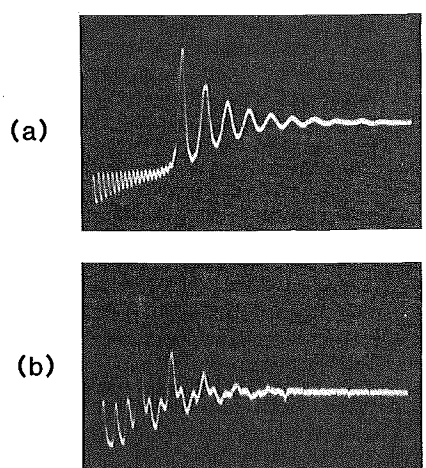
The ratio S_x/S_y can be measured accurately and enables values of the polarization cross-section ratio A to be deduced. From the results given for fibers containing erbium and neodymium A has values of 0.11 and 0.01, respectively, showing that these ions have very strong polarization anisotropy of the stimulated emission cross section.

(Poster paper)

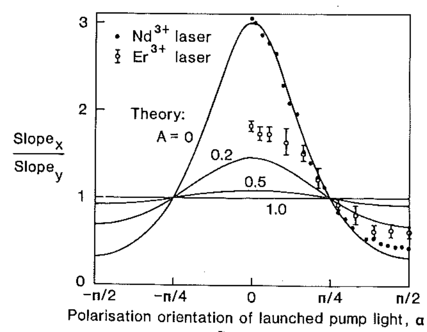
1. J. T. Lin, P. R. Morkel, L. Reekie, and D. N. Payne, "Polarisation Effects in Fibre Lasers," in *Technical Digest, Thirteenth European Conference on Optical Communication*, Helsinki (1987).
2. J. T. Lin, L. Reekie, and L. Li, "Single-Polarization Operation of a Nd^{3+}-Doped Single-Mode Fiber Laser," in *Technical Digest, Conference on Lasers and Electro-Optics* (Optical Society of America, Washington, DC, 1987), paper FP3.
3. D. W. Hall, R. A. Haas, W. F. Krupke, and M. J. Weber, "Spectral and Polarisation Hole Burning in Neodymium Glass Lasers," IEEE J. Quantum Electron **QE-19,** 1704 (1983).



TUJ25 Fig. 1. Measurements showing fluorescence depolarization, retained polarization of the residual pump, and the DOP of the laser output as a function of pumping power. The points represent measured values, and the solid lines are derived from the theoretical model.



TUJ25 Fig. 2. Typical relaxation oscillation patterns, each showing two orthogonal eigenmodes with different buildup times and oscillation frequencies. The initial part of each trace represents the stronger, which appears first and has been heavily attenuated by a nearly crossed polarizer: (a) $\omega_x/\omega_y = 6$ at $P_{ab}/P_{th} = 5$; (b) $\omega_x/\omega_y = 2.9$ at $P_{ab}/P_{th} = 7$.



TUJ25 Fig. 3. Experimental and theoretical values of the slope efficiency ratio as a function of launching angle showing a strong polarization anisotropy for Nd^{3+} and Er^{3+} ions in silica optical fiber.