Time variation of refractive index in the core of active fiber under pulsed optical pumping

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Abstract

The kinetics of refractive index change in active fiber under pulsed cladding-coupled optical pumping was investigated using interferometric technique. Relaxation processes after lasing threshold was observed.

Introduction

Rare-earth-doped fibres find a wide use in optical communication, due to their applications in amplifiers and lasers. A fiber is heated during the operation of the amplifier or the laser and refractive indices of the core and cladding are changed under a high power optical pumping. Different physical mechanisms responsible for this process were considered in recent experimental works [1, 2]. No investigation of their joint actions in photoluminescence and lasing regimes was performed up to date due to various temporal characteristics. In our work we present the results of the measurements of refractive index change rates, their dependence on the pump power, and a comparative analysis of the underlying mechanisms affecting the refractive index.

Experiment

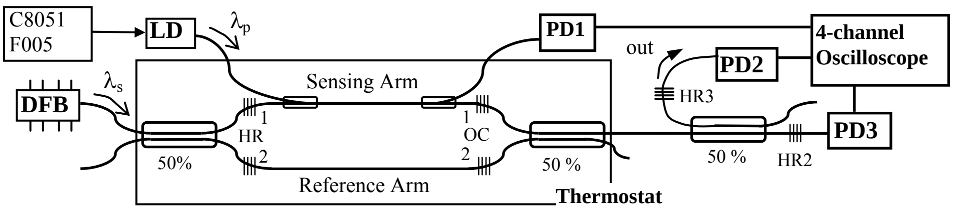

Fig 1: Experimental setup: LD – pump radiation (λ_p = 962 nm), DFB – source of probe light (λ_s = 1564,8 nm), C8051F005 – microcontroller, PD – photodetectors, HR, OC – fiber Bragg gratings.

We implemented the measurement technique, based on using a Mach-Zehnder interferometer assisted with a probe light (Fig. 1.). An emission of a DFB-laser at wavelength of 1564.8 nm with the coherence length of 150 m was propagated through a 50% splitter and directed to the arms of interferometer formed by two Yb^{3+}-doped fibers. The refractive index change due to pumping of a sensing arm leads to a variation in the optical path length difference between two waves of the probe light. The beat signal of these waves was detected by a photodiode (PD2 in Fig. 1) connected to a storage oscilloscope. For kinetics of relaxation processes in optical fiber to be investigated the pump radiation of multimode laser diode was modulated by square pulses. The modulation was driven by a microcontroller, with the waveform duration less then 5 μs.

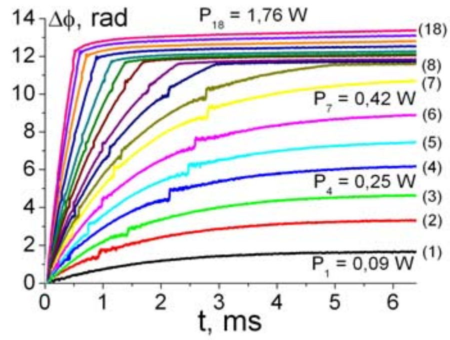

Fig 2: Dependence of phase shift on time after pump pulse switched on. Pulse amplitudes alternates from 0.09 W to 1.76 W

Figures 2, 3 shows the results of the phase difference measurements after switching on and off the pump power with the modulation period of 12.8 ms.

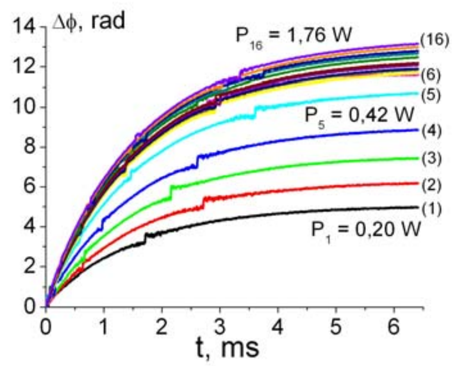

Fig 3: Dependence of phase shift on time after pump pulse switched off.

In our experiment the length of the active fiber was 3 m. The absorption of the cladding-coupled pump was 1.20 dB/m at the pump wavelength. The concentration of Yb^{3+} was 4000 ppm. A laser threshold was 0.46 W.

Using spectral filtering we investigated the laser operation before and after the lasing threshold. The main contribution to the refractive index change in the core of the active fiber is believed to be produced by the following effects: the excitation of resonant acoustic modes in the fiber and their relaxation, the dependence of fused silica refractive index on the temperature and the change in the population of the electronic states of Yb^{3+} acting through the difference in polarizability for transitions between the 4f-levels and 5d-shell. After lasing threshold is achieved the population inversion should be stabilized to a steady-state value, but we observe the additional relaxation processes. The values of the phase shift after threshold plotted from the origin of coordinates is depicted in larger Δφ-axis scale on fig 4.

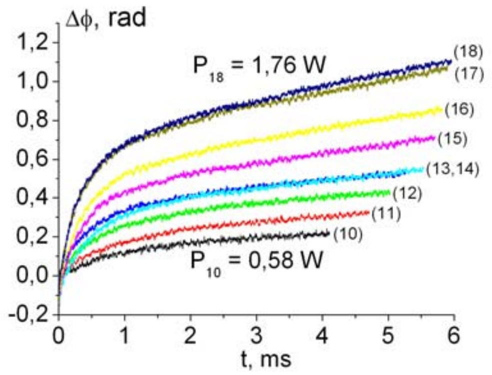

Figure 4: Dependence of phase shift on time after lasing threshold for different pump powers

These data is best fitted by function:

$$\varphi(t) = a\left(1-e^{-t/\tau}\right)+kt+b$$

, where all coefficients depend on pump power. The slope of linear part corresponds to a slow heating of the fiber, and exponential term corresponds to undetermined relaxation process.

There is pictured on fig. 5 the dependence of tau-parameter on pump power in comparison with relaxation oscillations decay time, calculated by expression $\tau_{relax} = \frac{\tau W_0}{W_p}$, where τ is Yb metastable level lifetime, W_p is the pump rate, W_0 is the threshold pump rate. The discrepancy between these magnitudes, greater then experimental error, allows us to suppose the presence of another relaxation mechanism, especially since relaxation oscillations of population inversion was also detected in beat signal. The model of this behaviour will be given later.

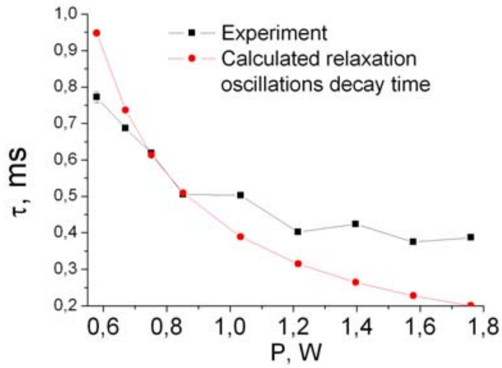

Figure 5: Dependence of τ-parameter on pump power

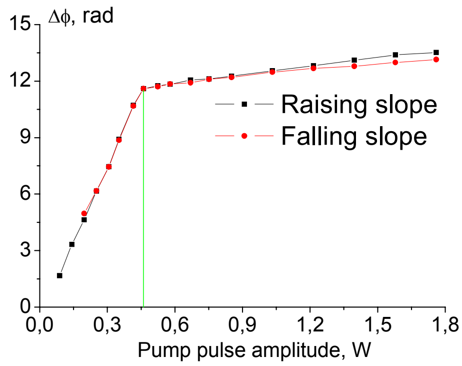

Figure 6: Dependence of full phase shift on pump power. The laser threshold is denoted by green vertical line.

The slope of the left part of the curve on fig. 6 is 27.2 rad/W, which corresponds to difference in polarizability of $1.64 \cdot 10^{-26}\ sm^3$ [3].

Conclusions

The proposed interferometric technique is the powerful tool for investigation of population dynamics in active ions in lasers and amplifiers. The measurements of nonlinear refractive index change in active fiber under pulsed optical pumping were carried out and kinetic parameters of medium response on probe signal was determined. The investigations of heating the fiber in larger time scale will be continued

References

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