COMPARISON OF ELECTRONIC AND THERMAL INDEX CONTROL IN YB-DOPED FIBERS FOR COHERENT BEAM COMBINING

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The pump/signal induced refractive index changes (RICs) in optical fibers can be used for coherent control of the optical phase in coherently combined fiber amplifier arrays. The RICs in cw or quasi-cw pumped rare-earth-doped optical fibers can be caused both by the thermal mechanisms (due to thermalization of the pumping energy) and a non-thermal effect due to population change of levels with a different polarizability (it can be described by Kramers-Kronning relation) [1-3]. Here we present the theoretical analysis with the aim to compare the contributions of the thermal and electronic mechanisms to the RICs induced in the Yb-doped fiber amplifiers under different pumping conditions (cw or pulsed pumping) and amplifying signal behaviour which are used for coherent beam combining.

Recently the electronic and thermal RICs in the Yb-doped amplifiers were examined by the all-fiber spliced Mach-Zehnder interferometer comprised the tested fiber in one of the arms [2,3]. The Yb-doped fiber was pumped at 980 nm. The relaxation dynamic of the RIC after the end of the pump pulse can be approximated by two-exponential decay corresponded to the excited-state decay (the electronic contribution) and the heat relaxation. The fractions of the electronic and thermal contributions to the RICs for the different amplifier regimes were examed.

The induced RIC in a double-clad Yb-doped fiber amplifier was theoretically modeled (both analytically and numerically). The model takes into account the following thermally assisted mechanisms of the index change: the conventional volume thermal index changes (“dn/dT”), the photoelastic effect, and the thermal expansion of the fiber. It is based on the solution of the heat conduction equations (with a radial heat flux for the fiber) and quasi-static thermoelastic equations (in the plane-stress approximation with free boundary conditions) that allow to evaluate of the index change distribution along the fiber. The boundary conditions with the fixed temperature or heat flux on the outer cladding surface were assumed. The population rate equation with saturation (by amplified spontaneous emission or an external wave) was examined to find the electronic RIC in the active core. The experimentally-determined thermal and electronic parameters (thermal gradient of the refractive index, polarizability difference of the Yb ions, and so on) were used for the estimations.

The electronic mechanism of the RIC was found to predominate under the thermal effect in the fibers in the pulsed pumping regimes with a low power (Fig. 1). The increase of the pump-pulse duration and/or pumping power leads to the growth of the core temperature, and the thermal-induced phase shift of the testing wave in the fiber grows and can be more stronger than the electronic RIC. The ratio of the thermal and electronic RIC depends on the core and clad radius, the heat flux on the boundary and other parameters. The amplified signal changing the population distribution and temperature profile inside the fiber leads to change of the ratio.

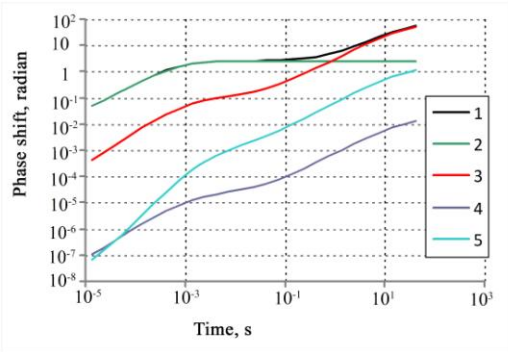

Fig. 1. Dependences of the phase shift of a probe beam on time (fiber length is 2 m, Yb concentration is $8{,}56\cdot10^{19}$ cm^{-3}, pump power is 0.145 W, core diameter is 3.6 μm). 1 is the summary phase shift, 2 is the electronic contribution to the phase shift, 3 is the thermal contribution to the phase shift due to thermo-optic coefficient, , 4 is the thermal contribution to the phase shift, associated with the elongation of the fiber, 5 is the thermal contribution to the phase shift, associated with the expansion of the fiber. Axes plotted on a logarithmic scale.

References

[1] M.J.F. Digonnet, R.W. Sadowski, H.J. Shaw, and R.H. Pantell, Opt. Fiber Technol. **3**, 44-64 (1997).
[2] A.A. Fotiadi, O.L. Antipov, and P. Mégret, Opt. Express **16**, 12658-12663 (2008).
[3] A.A. Fotiadi, O.L. Antipov, P. Mégret, In book *“Frontiers in Guided Wave Optics and Optoelectronics"* edited by B. Pal, INTECH, ISBN 978-953-7619-82-4, pp.209-234 (2010).