Light guiding in a fiber-coupled liquid crystal

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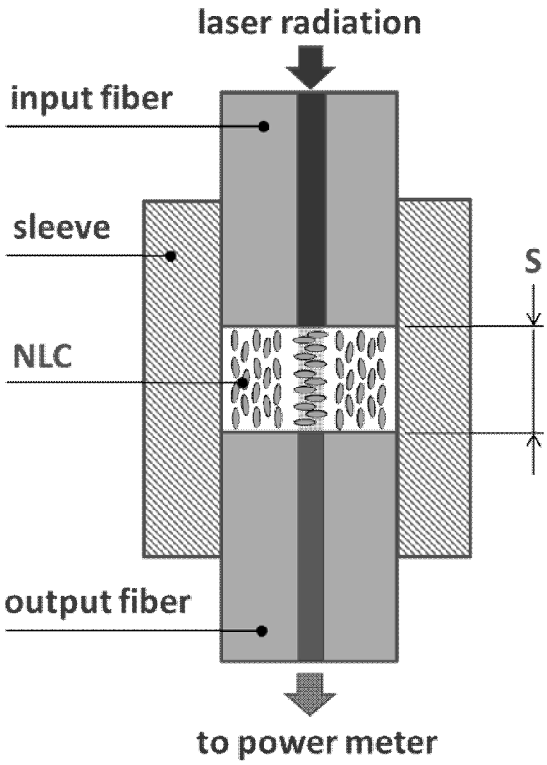
Among various soft matters, liquid crystals (LCs) have perhaps the most interesting and promising optical properties. LCs feature very high nonlinear optical susceptibility of complex orientation-electronic nature [1, 2]. Orientation order and anisotropy of LCs can be easily modified by applying relatively weak electro-magnetic fields and inducing thermal gradients [3]. Good quality optical contact between LCs and glass substrates is normally achievable. It makes LCs attractive optic media for research into nonlinear photonics and development of novel optic devices, including fiber-coupled ones. Thus a miniature fiber-coupled LC-based laser frequency converter was demonstrated recently [4]. It has a fiber input and a free-space output. An important task for further elaboration of such LC-based nonlinear photonic devices is transition to the in-line (fully fiber-coupled) design. In-line LC-based fiber-optic elements may be in demand for various applications ranging from ultra-compact laser systems to telecom technologies.

On the basis of the above, we studied experimentally feasibility of nonlinear fiber-to-fiber coupling via nematic liquid crystal (NLC). The experimental approach is illustrated in Fig.1. Two identical telecom single-mode optical fibers (core diameter ~ 8 μm) were terminated coaxially in a cylindrical sleeve filled with NLC. A room-temperature cyanobiphenyl-based (nCB) nematic mixture was used. The spacing *S* between the fiber end faces was adjustable from ~ 10 to 500 μm by means of a translation stage with a micrometer. To monitor the gap a CCD camera with microimage optics was used. A lengthwise slit in the mating sleeve enabled adjustment of the NLC capacity. A fiber-coupled laser diode at 1480 nm with output power tunable from few to 400 mW was used as a light source.



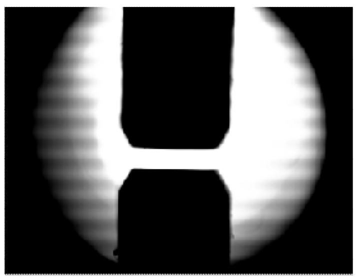


Fig. 1 Experimental fiber coupling arrangement: NLC – nematic liquid crystal, S – fiber spacing value (varied ~10 ÷500 μm). The right inset is a microimage of the gap (obtained by a monitoring CCD camera).

We discovered that strong optical coupling (loss ~ 1 dB) of two single-mode optical fibers separated coaxially by NLC can be achieved through a self-induced light guide despite a relatively large fiber-to-fiber spacing and a low optical power. This effect is due to light-induced reorientation of NLC molecules, which causes self-confinement of a propagating laser beam. Self-confinement of light in NLCs was already observed and explained earlier [2]. In our work this effect was for the first time exploited to achieve and study nonlinear fiber-to-fiber coupling and to demonstrate feasibility of development of NLC-based in-line fiber-optic elements and devices. Fig. 2 represents the measured transmission curve for fiber-to-fiber coupling via a 320-μm NLC-filled gap.

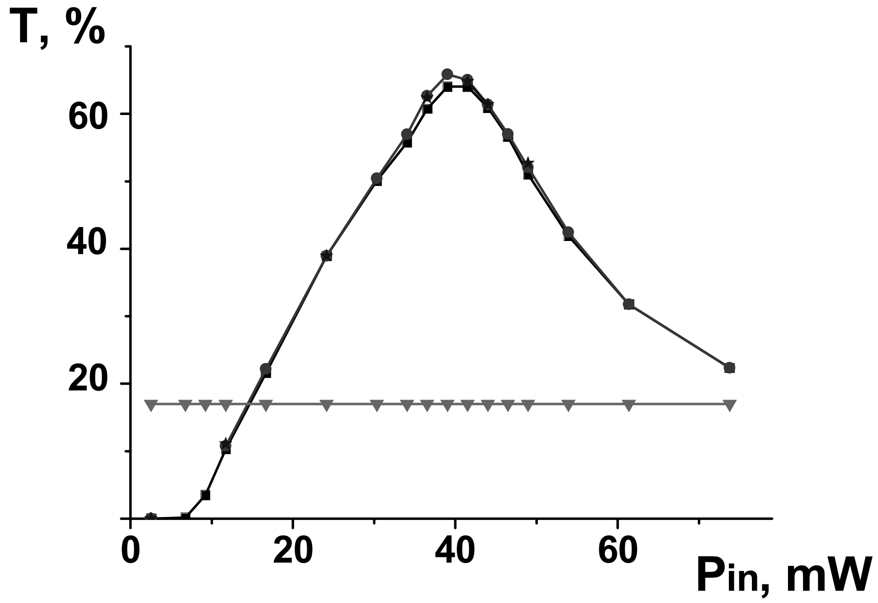


Fig. 2 Experimental transmission curve (dependence of fiber-to-fiber coupling coefficient on the input optical power) traced 3 times for reproducibility proof at $S \approx 320$ μm. The horizontal line marked by triangles is measured transmission of the same gap but filled with a refractive-index matching gel instead NLC.

Despite the huge fiber spacing equal to ~4 diffraction lengths, the transmission reached nearly 70% at a certain optical power level (~ 40 mW). The self-induced light guiding was enough stable over time and quite reproducible. The largest fiber spacing which still allowed strong optical coupling was estimated experimentally as nearly 450 μm.

The physics of self-triggered light guiding in NLC is supposed to be based on the balance between diffraction and self-focusing. However it differs from nonlinear light propagation in solids because of highly nonlocal response of NLC. Thus the critical power for the above balance in NLC is defined by an equation different from the Kerr case typical for solids [2]. In NLC the critical power varies with the beam waist. Self-focusing weakens (the critical power increases) as the spot-size reduces, thereby preventing collapse and stabilizing the self-trapped wavepacket in NLC.

The obtained results prove feasibility of strong nonlinear fiber-to-fiber optical coupling via nematic liquid crystals. It opens up possibilities for development of novel NLC-based in-line fiber-optic elements with such functionalities as laser frequency conversion, power limitation, and polarization control.

The work was partially supported by government programs (projects: NSh-6689.2016.2, 030720140005, and 030720140007).

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