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Optical bistability in nonlinear liquid crystalline directional coupler

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A polished fiber half coupler with a nematic liquid crystal as a multimode planar waveguide overlay has been investigated. Experimental results show an existence of optical bistability with contrast ~40% for laser power ~340 mW at $\lambda = 514$ nm.

1. Introduction

Due to its particular properties, liquid crystals represent potential materials for applications in nonlinear optics [1]–[4]. The nonlinearity is 6–10 orders of magnitude greater than nonlinearity of "usual" media. A nonlinear change in the refractive index in the nematic liquid crystal (NLC) arises mainly from the reorientation of anisotropic molecules and changes of the order parameter and density owing to the temperature. These phenomena produce large refractive index changes ($\Delta n \approx 0.2$), which allow the observation of nonlinear effects for low power laser input.

Self-focusing [1], intensity-dependent scattering of light [5] and bistability [6] have all been observed. The nonlinear directional couplers in which two planar waveguides were separated by nematic liquid crystal have been described as well theoretically [7], [8] and observed in experiments [9].

In this paper, we present a coupler that consists of a NLC planar waveguide and optical fiber. Intensity-dependent changes of the effective refractive index in the LC cause changes of the coupling coefficient between fiber and multimode NLC waveguide. Therefore the transmission of the analysed coupler is nonlinear. Due to the properties of the NLC waveguide the optical bistability has been also obtained.

2. Liquid crystalline coupler

The geometry of the investigated coupler is presented in Figure 1. An optical fiber is mounted in a silica glass block and polished close to the core. The overlays con-

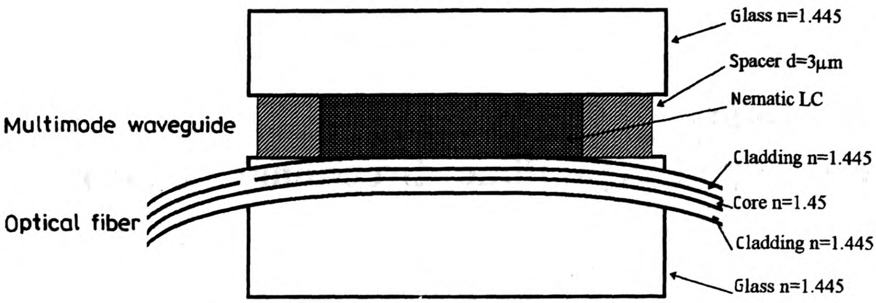

Fig. 1. Configuration of nonlinear directional coupler

sist of a NCL layer at thickness $d = 3$ μm, being multimode planar waveguide.

Two forms of coupler were developed:

– Coupler (1) consists of an optical fiber SM1300 (which is single mode for $\lambda = 1.3$ μm and it has few modes for $\lambda = 514$ nm) and NLC E7 standard mixture.

– Coupler (2) comprises optical fiber SM600 (with two modes for $\lambda = 514$ nm) and nematic 6CHBT which has different elastic constants than E7.

The ordinary and extraordinary refractive indices of E7 and 6CHBT NLC are $n_o = 1.5216$, $n_e = 1.7462$ for $\lambda = 589$ nm at 20 °C. The thickness of NLC film was defined by MYLAR spacer. In the first configuration the orientation of the NLC molecules was not strictly controlled. In the second configuration we used surfactant CTAB which forced the homeotropic alignment of NLC.

The coupling between waveguides in the directional coupler depends on effective refractive indices of separated waveguides. The analysed NLC planar waveguide for the wavelength $\lambda = 514$ nm, and homeotropic alignment and TE polarisation of light (with the refractive index of NLC equal to its ordinary index) have 6 optical modes with different effective refractive indices. The difference between effective refractive indices of the lowest mode in NLC waveguide and the highest mode in SM1300 fiber is one order of magnitude larger than difference between effective refractive indices in SM1300. Therefore the coupling for these two waveguides is very low.

If the refractive index in NLC waveguide is increased (owing to the rotation of the molecules), then one new mode in NLC waveguide can be formed. In this case the difference between effective refractive index of this new mode in NLC waveguide and the lowest mode in SM1300 fiber is very small. This allows almost complete coupling of light between two waveguides in the directional coupler.

The change of the refractive index in NLC planar waveguide can be stimulated by changing the light intensity due to the nonlinear effect. In our configurations the light launched to the optical fiber changes the refractive index profile in the NLC waveguide. If the input intensity is low then the light remains in the same output arm of the coupler. If the input intensity continues to increase (the refractive index profile is changed) and a new mode is formed then nearly all light can be coupled to the NLC waveguide.

The optical bistability for directional coupler with Kerr-nonlinearity and without any optical feedback have never been observed. In our coupler the liquid crystal allows to observe optical bistability. It is caused by the long distance interaction between molecules. Theoretical background of this phenomenon is presented in [10].

3. Experimental results

The experimental arrangement is presented in Figure 2. An argon laser, with linearly polarised light was operating in spectral line $\lambda = 514$ nm. A microscope objective was used to launch the incident beam into the optical fiber. The launch efficiency was ~70% for SM1300 and ~50% for SM600. The mirror reflected 8% of the laser beam in order to control the incident intensity. A fiber polarisation controller was used to change the light polarisation in the input arm of the coupler.

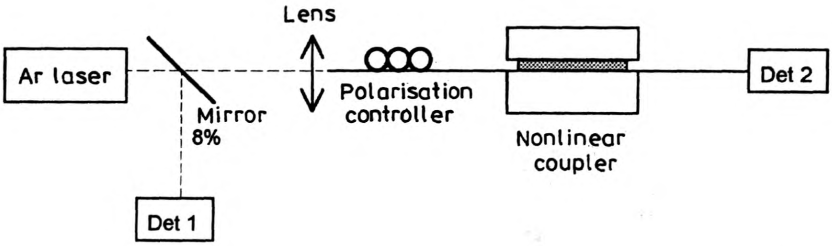

Fig. 2. Experimental arrangement for investigation of the nonlinear liquid crystalline coupler

The investigation started using the laser at the low power (~50 mW). We could control the polarisation of light in optical fiber by polarisation controller. This is necessary in order to adjust the polarisation in the optical fiber (close to the coupler) similar to TE or TM modes, which exist in the planar waveguide. The change of thickness of LC core produced by pressing both glass blocks allowed maximum coupling of light from fiber to the planar waveguide. Next, a minimum coupling between both arms was obtained by reducing the thickness of LC core (a minimum of scattered light in planar waveguide was observed). A characteristic curve of the intensity at the end of the optical fiber was plotted by increasing and decreasing light intensity emitted by the laser in the range of 0–1.2 W.

For coupler (1) optical bistability was observed for a laser power of ~820 mW. The contrast of bistability was ~9.5% (Fig. 3). In coupler (2) contrast of about 41.4% was observed for an input intensity of ~340 mW (Fig. 4). The input intensity threshold (for which the switch in power was observed) was independent of time of increasing or decreasing of laser power. It means that the presented optical bistability is induced by reorientational effect not by thermal effect.

In conclusion, the contrast of bistability depended on number of modes in optical fiber. A liquid crystal with a high order parameter structure and a high nonlinearity allowed the observation of bistability at much reduced intensity. The main problem encountered during the experiment was a fluctuation of polarisation

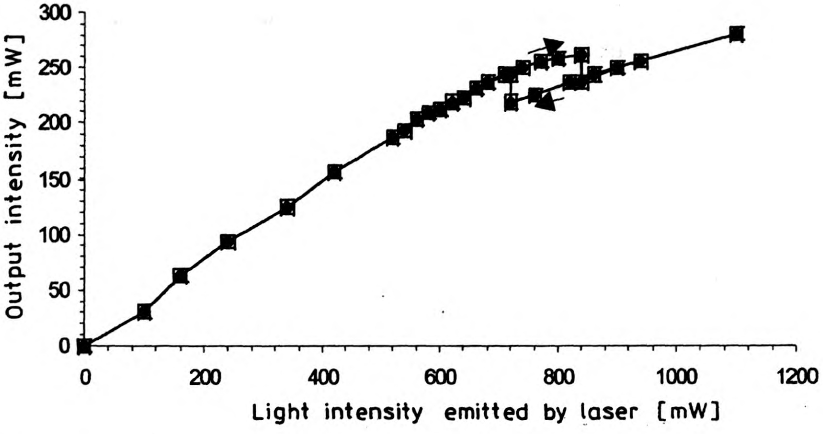

Fig. 3. Characteristic curve of intensity bistability for the nonlinear coupler (1) comprising LC–E7 and optical fiber SM1300

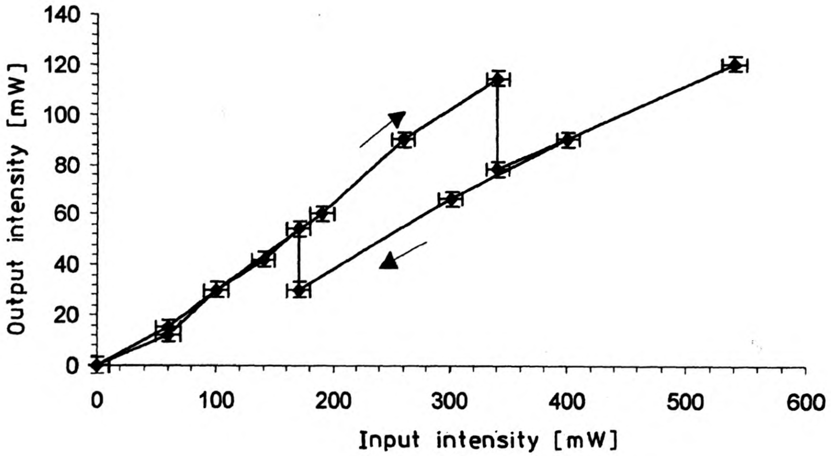

Fig. 4. Characteristic curve of intensity bistability for the nonlinear coupler (2) comprising LC–6CHBT and optical fiber SM600

in the optical fiber which limited the time of repeatable observation. For both couplers this time was ~ 15 min. Therefore, in order to improve the properties of the device a single mode fiber maintaining polarisation may be incorporated into the structure.

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