Frequency dependence of electric field tunability in a photonic liquid crystal fiber based on gold nanoparticles-doped 6CHBT nematic liquid crystal

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Abstract—In this paper, we investigate an external electric field frequency influence on a photonic liquid crystal fiber (PLCF) based on a gold nanoparticles (NPs)-doped nematic liquid crystal (LC) and its response to the external electric field. We used a 6CHBT nematic LC doped with 2-nm gold NPs in a weight concentration of 0.1%, 0.2%, 0.3%, and 0.5%.

Over the last two decades photonic crystal fibers (PCFs) have gained an increasing research interest. Only in the last 10 years more than 17,000 papers have been published on PCFs compared to 11,000 in the first decade[1-3]. The history of liquid crystals (LCs) is much longer and its origins date back to 1888 when the first observation of liquid crystalline phase were made by Fritz Reinitzer. However, in the last 10 years the number of works published on LC has edged down to 224,000 compared to the previous decade (229,000)[4-6].

In recent over 15 years [7], there has been a growing interest in applying LCs into photonics crystal fibers, since manufacturing not only planar waveguides but also optical fibers with LCs that combine their interesting tuning properties in the form of photonic liquid crystal fibers (PLCFs)[8-9]. In the last 5 years over 1,600 papers have been published on the PCFs and LCs topic, and in the previous 5 years intervals the number of publications was as follows: 1,100, 600, 130, respectively. There is a clear upward trend indicating still a potential in developing of this particular research direction.

Recently [10-13] our research activities have been concentrated to increase an applicability potential of PLCFs by doping LCs with appropriately selected nanoparticles so that the resulting material as a composite obtains parameters more relevant to its potential application in telecommunications. We have analysed switching times of such systems composed of PCFs and LCs doped with various types of NPs [11-13]. Also, relationship between type, concentration and size of a NP dopand in LC and its influence on the effective PLCF was investigated. The results obtained made it possible to significantly reduce the switching times and had a positive effect on electrical control parameters of such systems, allowing to reduce threshold voltages used for their control[11]. Moreover, temperature sensitivity of LCs has been investigated [12] and in particular an influence of NPs doping on the nematic-isotropic phase transition temperature [12]

In this paper, we present the so far not discussed aspect of the controlling external electric field, namely frequency of the electric field and its influence on the reaction of the system composed a PCF composite filled with NPs-doped LC. The measurement system included a PLCF sample, as well incoming and outgoing optical fibers. A laser operating at a wavelength of 675 nm was used as a light source and an Ocean Optics power meter was used as a detector. The tested sample was placed between two plates to which the control voltage was applied after appropriate amplification so that the generated electric field was of the order of 1V / um in order to obtain reorientation forced by the external electric field (Fig. 1). The range of frequencies used during the experiment was determined by the amplifier's high-frequency capabilities and the doped LC relaxation times. The frequency range varied from 10 Hz to 0.3 MHz.

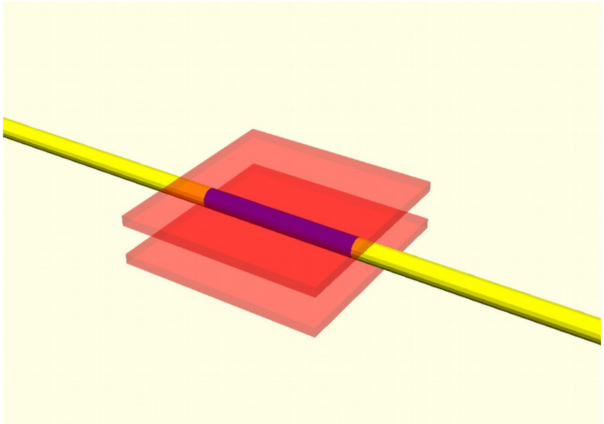

Fig. 1. Fig. 1. Setup of PLCF (blue section of yellow optical fiber) with NP-doped LC response for electric field with various modulation frequencies placed between two plates(red)

To determine an influence of different frequencies on the PLCF responses, a common wavelength in PLCF transmission spectra for all samples is needed. For this purpose, spectral measurements of the transmission of PLCFs filled with a mixture of a 6CHBT nematic LC and gold (Au) NPs of various concentrations were performed (Fig. 2). As it can be seen in Fig. 2, transmission spectra without doping as with 0.5% doping have similar spectral characteristics. For intermediate values of the Au NPs doped LC, additional transmission bands arise and the existing ones widen relative to the extreme values of NP Au doped LC. Therefore, a laser source operating at the wavelength of 675nm was selected.

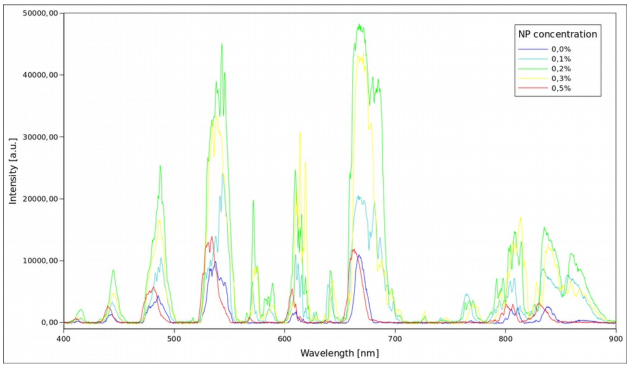

Fig. 2. Transsmision spectra for PCF infiltrated with Au NP doped LC

An influence of different modulation frequencies of the applied external electric field on response times of the photonics crystal fiber infiltrated with LC mixtures with different concentrations of Au NP are presented in Figures 3-5. The frequency signal in range from 10 Hz to 0.3 MHz was generated by a waveform generator and modulated with 1 Hz for rise and fall time measurements.

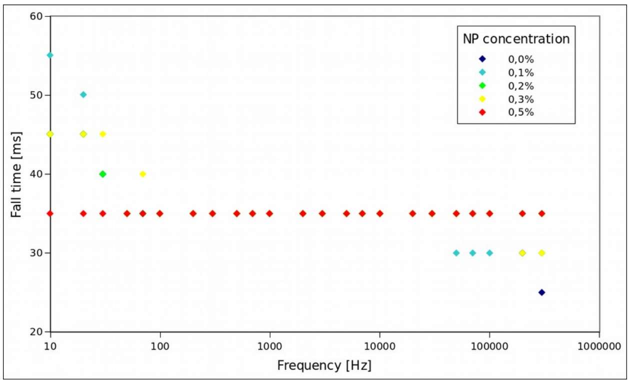

Fig. 3. PLCF fall times induced by external electric field for wide frequencies range

As shown in Figure 3, for a concentration of 0.5% wt. Au NPs in LC, the relaxation times practically do not depend on the modulation frequency. However, with the lower percentage of NPs in LC, the relaxation times for higher frequencies decrease from 35 ms for medium frequencies to 25 ms for 0.3 MHz for undoped LC. By using lower modulation frequencies of the control voltage, there is a clear increase in relaxation times from 35 ms for medium frequencies to 55 ms for 10 Hz for a 0.1% wt. NP LC doped.

The results of the rise time measurements (Fig. 4 and 5) in function of frequency of the applied control voltage depend on the percentage of NP in the LC and show a similar relationship as for the relaxation (fall) times. Closer analysis of the results shows that 0.1% wt. and 0.2% wt. Au NPs-doped LCs show the shortest rise times. For doping percentage of 0%, 0.1% wt. and 0.2% wt. NPs in LCs for lower and medium frequencies, the rise times are relatively constant and are equal to 1.6 ms, 1.1 ms, 1.1 ms respectively, while for higher frequencies there is an increase in rise times to 5.9 ms, 4.0 ms and 4.1 ms respectively. For doping percentage of 0.3% wt. and 0.5% wt. NPs in LCs, there are large values of rise times for lower frequencies, minimal values for medium frequencies and an increase for higher frequencies are clearly visible. For 0.3% wt. NP in LC, the rise times are 3 ms, 2.2 ms, and 5.7 ms for low, medium, and high frequencies, respectively. For 0.5% wt. NP in LC, the rise times are 50 ms, 22 ms, and 4.4 ms for low, medium, and high frequencies, respectively.

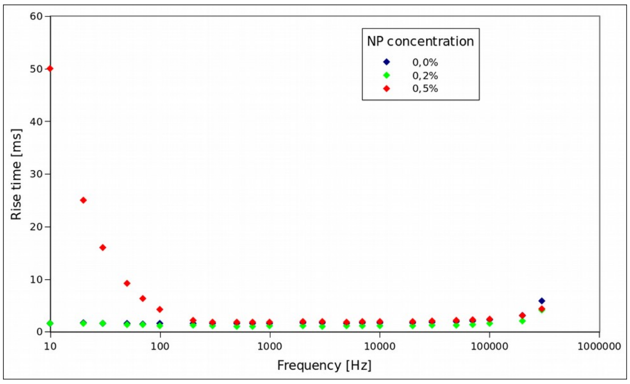

Fig. 4. PLCF rise times induced by external electric field for wide frequencies range for concentrations 0.5% wt. to 0.2% wt. and 0% wt.

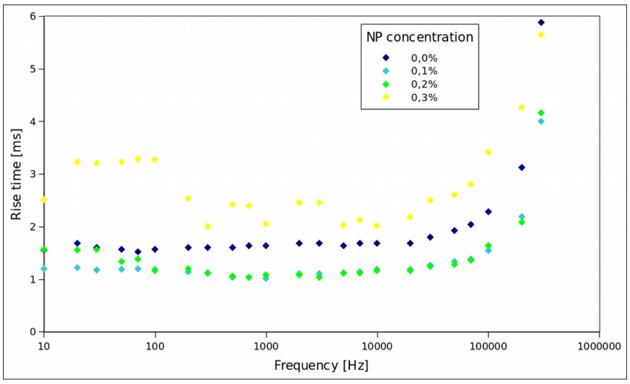

Fig. 5. PLCF rise times induced by external electric field for wide frequencies range for concentrations 0% wt. - 0.3% wt..

Based on the results obtained one can determine a suitable frequency range of the control voltage for the PCF infiltrated with the NPs-doped LC and percentage concentration of the dopant in the LC. For the 6CHBT nematic liquid crystal doped with 2nm Au nanoparticles, the optimal frequency range for the control voltage is between 0.5 kHz and 10 kHz. In this range, minimal values of rise and relaxation times can be simultaneously achieved. Due to the characteristics for the rise times, it is possible to determine the optimal percentage of Au NP dopand in LC and it is equal to 0.1% wt. of the Au NP in the 6CHBT LC.

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