

Ultrafast optical switching for polyarylates with allylic groups by Nd:YAG Sagnac interferometer

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In this paper, an ultrafast optical switching for thin polymer films (polyarylates with allylic groups) is presented. It was realized using the Nd:YAG Sagnac interferometer. Investigated polymers appeared to be suitable candidates for elements of integrated optical telecommunication systems.

Keywords: optical materials, polymers, optical switches, nonlinear optics.

1. Introduction

All optical switching is one of the most important processes in optical telecommunication. It is realized today in many configurations – both for organic and inorganic materials. In this paper a photonic switching is presented which is based on nonlinear polymers, polyarylates with allylic groups, generated in nonlinear optics loop mirror (NOLM) setup with Nd:YAG pulse laser. Recently, telecommunication optical systems are strongly conditioned by the development of fast data transfer [1]. New all-optical devices are constructed. Fast reaction on changes of the external electric field of nonlinear optical polymers makes these materials very suitable for such applications. In order to measure nonlinear parameters of novel materials, different optical techniques are used [2]. Polymers have appeared to be good candidates for producing hybrid structures for light beam control in, *i.e.*, Sagnac, Mach–Zender, UNI, SOA configurations [3, 4]. All-optical interferometric operations are recognized as optimal tool in photonic signal processing [5–8].

Presently, there is an intensive search for novel nonlinear optical (NLO) materials that may be used to design and prepare improved waveguide devices for nonlinear

optical applications. Organic materials offer a number of advantages over inorganic crystals because of their high and ultra fast nonlinear response and a low dielectric constant, as well as the enormous design flexibility allowed by molecular engineering. Some novel strategies are now being actively pursued to optimize physical and nonlinear performance – the guest-host approach, and – on the other hand – polymers with side-chain groups. The main goal is to obtain a good medium for all-optical applications, by enhancing 3-rd order nonlinear Kerr effect. New polymer materials: polyarylates with allylic groups with *p*-nitroaniline in guest-host configuration has been synthesized [11]; they exhibit a promising performance in NLO applications and acceptable properties for technological preparation of channel waveguides.

2. Experimental setup

For nonlinear switching measurements we used the Sagnac interferometer, the Babinet–Soleil compensator and a beam attenuator. As a source of light we used a pulse laser (Q-switched Nd:YAG) with SH 532 nm and 9 ns duration and maximum power of 2.7 MW. Nonlinear switching in the Sagnac interferometer is based on two opposite parallel light beams passing through the sample – the first one with low intensity of light and the second one with high intensity that generates the nonlinear effect.

The sample and the attenuator were placed asymmetrically so that both pulses never are at the same moment in the sample. The 9 ns pulses correspond to about 2.7 m in space. Therefore the interferometer mirrors must be located in an adequate distance to guarantee time separation of pulses passing through the sample. The experimental setup is shown at Fig. 1.

A high energy pulse in the laser output passes through a rotating $\lambda/2$ plate so that the polarization is changed to the circular one and then passes through the polarizer turned by an angle of 45° . Intensity of light can be fluently regulated by the rotating $\lambda/2$ plate. Polarizing beam splitter (PBS), splits beam into two beams, each 50% of power, but of different polarizations. The first beam passes first through the sample and subsequently – through the attenuator, where 90% of its power is lost. The second one of its full power passes through the sample and next through the attenuator. Low optical power beam generates only standard phase shift in sample without any nonlinear effect. The high intensity light beam passing through polymer sample generates not only a standard phase shift but also an extra nonlinear phase shift (Kerr effect) depending on the intensity of light. The geometry of the interferometer causes that both beams never pass through the sample at the same moment and only one changes its phase. Both beams pass through the sample precisely in the same place, so all thermal effects and other low relaxation changes of the refractive ratio have the same impact on both waves. At the end both beams come back to PBS and interference is observed at two different outputs.

The methodology of light switching is based on the calibration of the interferometer as to reach minimum or maximum of the interference at the output 1 for low intensity

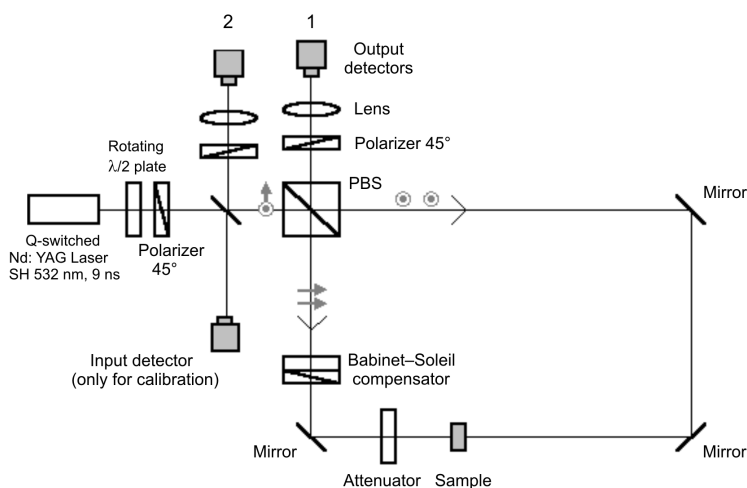


Fig. 1. Scheme of the measurement setup – asymmetric Sagnac interferometer.

of light on the detector. In the first case, when the experimental setup was directed to achieve minimum of the interference (during the increasing of the beam power), the normalized signal on the detector increases faster than in linear case (Kerr nonlinearity) and reaches its maximum when nonlinear phase shift is π . In the second option, when the beam power is increasing, normalized signal on the detector decreases and reaches its minimum for the nonlinear phase shift equals to π . Babinet–Soleil compensator was used because samples should have at least 2 cm of thickness to reach this value.

The minimum of signal at the output 1 corresponds to the maximum at the output 2 because the interference images at outputs are moved by π .

The basic theory of nonlinear properties of π -conjugated organic materials emphasizes that the conjugation length can enhance the electron delocalization in molecules responsible for large values of hyperpolarizabilities. An introduction of allylic groups in the polyarylates chain increases the conjugation of the system. Several reviews [9, 10] describe a variety of polymer systems including guest-host systems, side-chain polymers, main-chain polymers and cross-linked systems obtained by thermal and photochemical methods with different content of chromophores. In this work, we have connected the first and the last polymer system together.

UV sensitive polyarylates based on chalcones with allylic side chain (photosensitive polymers) were obtained by interfacial polycondensation of special monomers, bisphenols A and a mixture of aromatic acidic chloride.

A detailed description of synthesis and properties of polymers mentioned above was published in the work [11]. Final phases of synthesis of particular compounds are presented in Fig. 2, and their basic chemical properties are shown in the Table.

The introduction of allylic groups: two (polymer 2) or one (polymers 4, 5, 6) into the structure of chalcone allows to trip chromophore-*p*-nitroaniline and receive

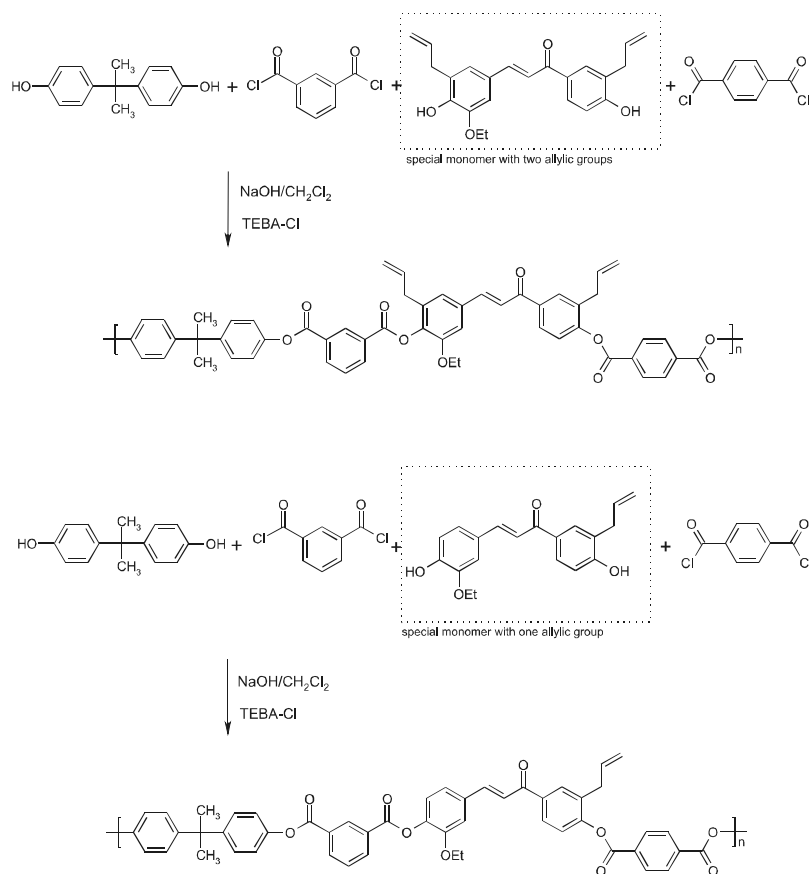


Fig. 2. Basic formula of polymer synthesis: polymer 2 (upper part) and polymers 4, 5, 6 (lower part). Polymers 4, 5, 6 have the same main chain as polymer 2 but different content of a special monomer.

Table. Basic properties of four polymers used in the experiment.

Polymer notation	Percentage of monomer [%]	Intrinsic viscosity η [100 cm ³ /g]	Glass temperature [°C]	Temperature of decomposition [°C]
2	8	0.915	120	231
4	10	0.770	102	252
5	8	0.673	111	245
6	6	0.863	120	246

a stable guest–host polymer system. Irradiation of polyarylates does not require the use of a photoinitiator, despite of the relatively small content of photosensitive monomeric units in the polymer chain (polymers 4, 5, 6 with different content of a special monomer) – see the Table. The presence of allylic groups in special monomers decreases the time of photo-cross-linking reaction in the polymer. It is well known that

photo or thermal-cross-linking reaction of polymers increases the relaxation time of NLO systems.

The light switching was observed on the control interference fringes when intensity of the beam was strongly changed – Fig. 3. This switching is caused by nonlinear properties of the polymer material. The changes of detected transmissions of the split beams versus power are presented in Fig. 4.

In order to clarify the results shown in Fig. 3, we have divided them into two even groups sorted by the polymer type. The letter *N* in the legend represents the *p*-nitroaniline (PNA) added to the polymer solution (guest–host) to increase the optical nonlinearity. The results with the *sw* mark in the legend represent normalized transmissions at the 2nd output of the Sagnac interferometer and they continue to decrease with increasing normalized power. The results without *sw* represent normalized transmissions at the 1st output and they increase with the normalized power grow. In the pure linear case the normalized transmissions at both the outputs should be constant and should not change with the normalized power.

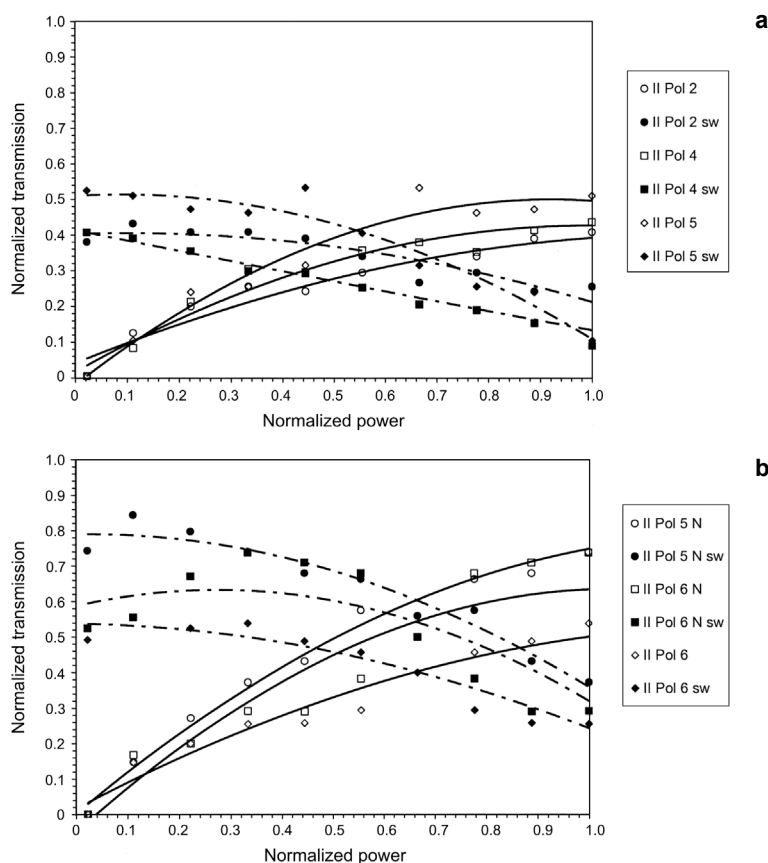


Fig. 3. Light switching – experimental results by the Sagnac interferometer for selected polymers. The accuracy of the (normalized) transmission measurements is of the order of 0.05.

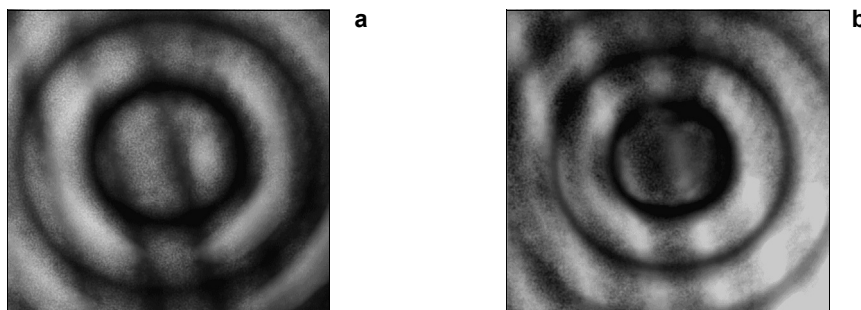


Fig. 4. Light switching in the Nd:YAG Sagnac interferometer – interference fringes at two different outputs (**a** and **b**).

In other words, in the linear case the results from the 1st output should oscillate around zero while those from the 2nd output should oscillate around 0.5–0.7 depending on the initial value of the normalized transmission at low normalized power.

We see that the normalization was introduced in order to ensure that only nonlinear effects be seen in Fig. 3. Without normalization of the experimental measurements, even in the pure linear case, when interference fringes at both the outputs of the interferometer do not move with increase of the beam power, there would be always an increase of the transmission due to increase of the beam power. In that case the results would be incomparable and indistinguishable from the linear ones.

Due to the higher changes in the normalized transmission with respect to the power growth the higher nonlinearity occurs and this is confirmed for polyarylates with PNA (Fig. 3**b**).

Values of nonlinear refractive ratios n_2' were measured by means of a similar method for selected polymers only and can be found in [12].

3. Conclusions

We have demonstrated possibility of all-optical switching in Nd:YAG Sagnac interferometer with nonlinear polymers – polyarylates with allylic groups. Nonlinear optics properties caused that investigated polymers are suitable candidates for further research to produce all optical switching devices as elements of integrated optics telecommunication systems. Structure of investigated polyarylates caused differences in values of nonlinear refractive ratios. Allylic groups caused better photocrosslinking in UV light so *p*-nitroaniline is better trapped and mechanical properties of layers are improved. The better entrapment of PNA leads to potentially higher EO effects after polarization process. However 3rd order optical nonlinearity does not require any polarization. The optical Kerr effect is much higher when PNA is introduced to the polymer.

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