Photonic Device Applications from Organic Functional Materials

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Advantageous photonic properties of organic materials for photonic use are denoted basing on linear and nonlinear polarizabilities of various types of bound electrons in those material systems. One of the typical linear photonic polymer application is polymer optical fiber including graded index polymer optical fiber (GIPOF). Dye doped polymer optical fiber amplifier is one of extended application. Organic nonlinear optical devices play a lot of important roles as key devices surrounding POF system applications. Electro-Optic (EO) modulator, EO switch, frequency converter etc. are included in.

1. Introduction

Ultra fine technology for semiconductor devices is ultimately proceeding into no outlet stage. Functions of those semiconductor devices come from free carrier behavior at various boundary conditions involving interface structures and impurity distributions.

On the contrary almost organic materials have no bulky free carrier but they have many kinds of spatially wide spreading orbital bound electrons which give large polarizabilities in light wave electric field. Especially nonlocalized conjugate pi-electron system gives one of the most functional organic for various optical nonlinear effects. They have large charge transfer axis length and exhibit ultra high speed response time up to femto second order. Also luminescent molecular materials system in dye may be constructed by stimulated absorptive and radiative dipole transition which is effective for light amplifications and lasing behaviors. Additionally spatial localizations of released carriers in organic materials prepare photorefractive effect.

2.Basic concept

Of course microscopic electronic process of organic materials in light wave electric field is described by quantum mechanics. Macroscopic polarizability is given by statistical expression as shown in Table 1.

Table 1 Polarization by bound electron

$$P_i=\varepsilon_0(\chi_{ij}^{(1)}E_j+\chi_{ijk}^{(2)}E_jE_k+\chi_{ijkl}^{(3)}E_jE_kE_l+\cdots\cdots)$$

$\chi^{(i)}$: i-th order complex polarizability

E : Electric field of light wave

Real polarizability :
- virtual transition
- high speed response

Imaginary polarizability :
- real transition
- stimulated absorption & emission
- light amplification, laser

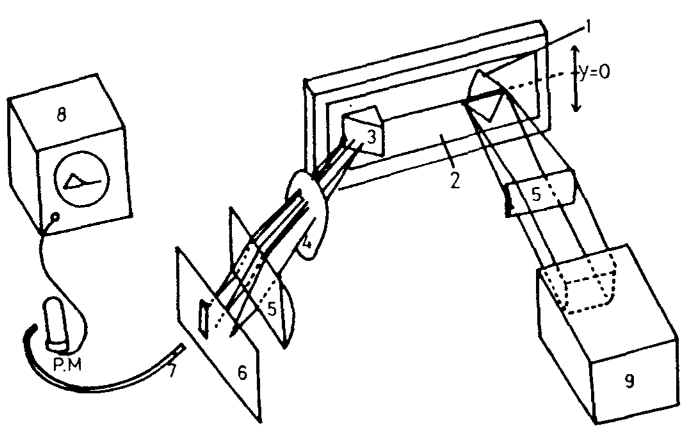
Real component of the complex polarizability means virtual transition which cannot defined by real transition states of perturbation theory of quantum mechanics. The process is completed by ultra-high speed non-real absorptive behaviour of bound electrons. Imaginary component of the complex polarizability comes from real transition of electron which makes quantum mechanically defined real absorption and emission.

The first order polarizability means linear optical process, and the second and the third order polarizabilities express the nonlinear optical responses. The linear process includes optically passive and active behaviors of materials. Nonlinear polarizabilities prepare a lot of colorful phenomena which are fantastic and interesting from both academic and practical point of views.

3. Linear polymeric waveguide devices

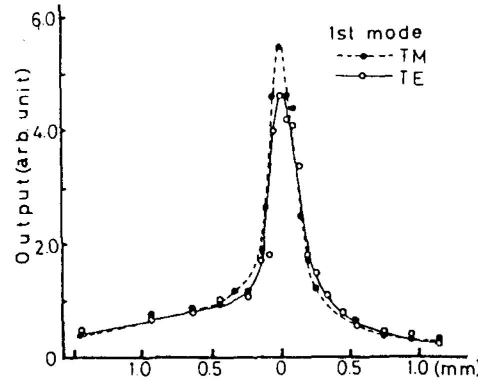
Recent progresses of optical fiber networks and their applications to multi-media society are requesting popularization of low cost interactive user end installations with high performances. Graded index polymer optical fiber (GIPOF) network with organic key devices is the most promising system. Y. Koike is the most active researcher on photonic polymer applications. His GIFOF is now installed on BOEING 777 aircraft successfully via High Speed Plastic fiber Network (HSPN) Consortium in USA. Active polymeric waveguides are also very interesting . Thin film waveguide dye lasers are targeting compact tunable low cost lasers. Fig 1 (a) and (b) show one example of the waveguide dye laser with corner reflecting resonator and its amplifier characteristic respectively.

Active dye doped GIPOF amplifiers were also developed by our group recently for the first time. Basic structure is the same as GIPOF as shown in Fig 2. Rhodamine B dye is radially concentrated around the core center of the fiber. Several ppm concentration of the dye gives high gain amplification up to 30 dB within 1 meter length at optimal condition of doubled Nd:YAG laser pumping.



1:squared prism, 2:polymer waveguide with dye, 3:prism for output, 4:lens, 5:cylindlical lens, 6:screen, 7:optical fiber, 8:oscilloscope

(a)Experimental illustration



(b) Amplifyung and lasing characteristics

Fig.1 Thin film waveguide laser. (a)Experimental illustration. (b) Amplifyung and lasing characteristics.

4. Nonlinear polymeric waveguide devices

The second order and the third order nonlinear properties of the polymeric materials are also very attractive for practical applications. Especially research field building up of the second harmonic generation (SHG) for the short wave light source application by non-centrosymmetric nonlocalized conjugate pi-electron system was initiated at the beginning of 1980. Theoretical molecular designs and synthesis realized a lot of new superior materials. Crystallization of those nonlinear molecular (NLOM) is one important field and guest-host system between NLOM and photonic polymer is the other useful concept.

Poled polymer waveguide for SHG is a typical application of NLO photonic waveguide device. Fig.3 shows a typical waveguide structure of poled polymer thin waveguide SHG device[5]. Disperse Red 1 (DR1) NLOM was polymerized as side chain structure to methylmethacrylate (MMA) main chain polymer. Poling process to align side chain molecular was carried out with spin coated film on a Pyrex glass substrate at glass transition temperature of the polymer system in a corona discharge chamber. The same technique can be applied to Electro-Optic (EO) modulator waveguide device.

In the practical application, because refractive index of polymer is usually low in comparison with inorganic materials, high speed modulation con be possible up to femto second order connecting with functional non-localized pi-electron behavior.

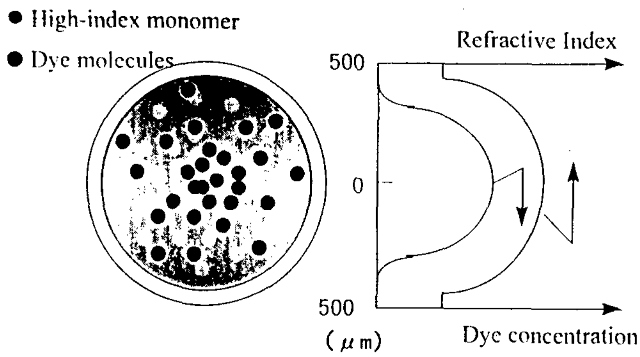


Fig.2 Index and dye concentration profiles of graded index polymer optical fiber amplifier.

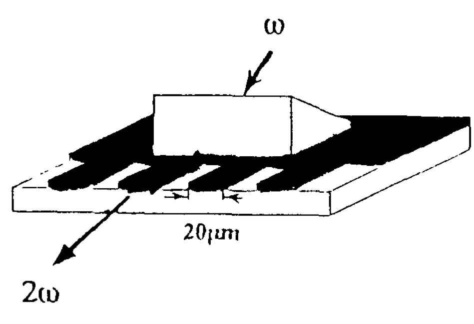


Fig.3 Illustration of SHG channel waveguide by corona-poled polymer film.

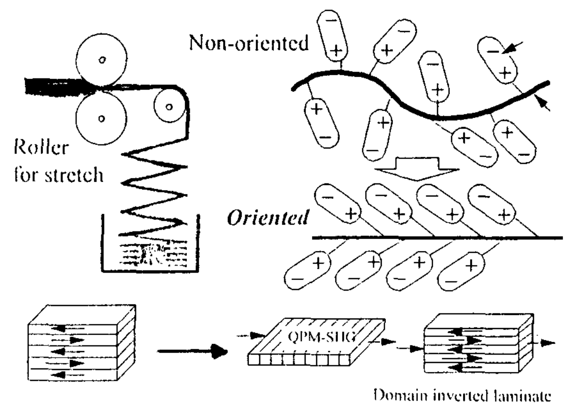


Fig.4 Novel side chain polymer NLOM alignment.

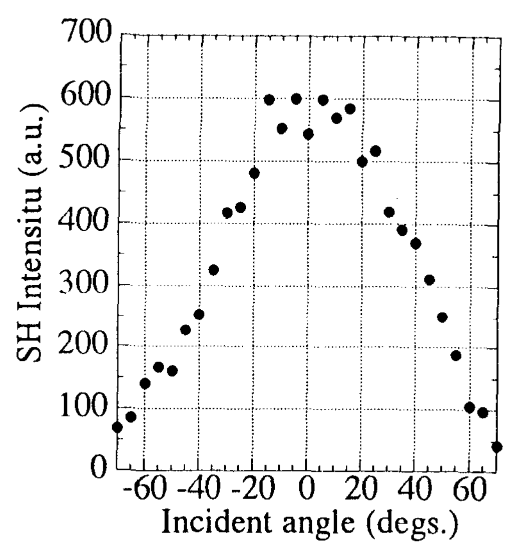
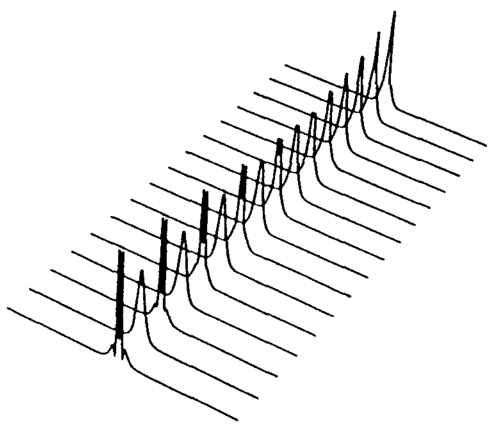


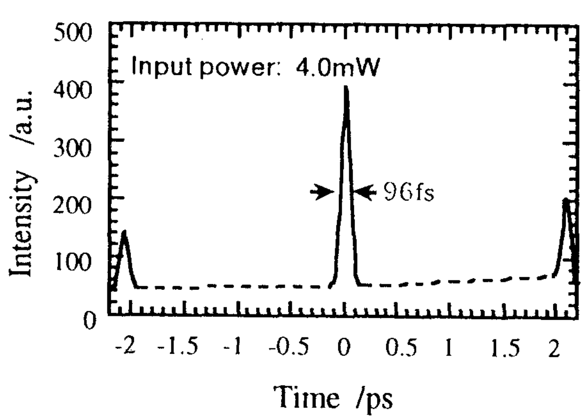
Fig.5 Maker-fringe pattern of d_{11}.

Recently a novel alignment method was invented for NLO polymer film preparation. The principle of the method is shown in FIg.4. Measured Maker fringe curve on the aligned film is shown in Fig.5. The film con be mechanically drawn and laminated by paired roller down to several microns in thickness. Inversely stacking of the film can prepare domain inversion structure for quasi-phase matching SHG device. Many new resarch fields will happen surrounding this new discovery for example theoretical modeling of orientation mechanism in physics and succeeding suitable material designing in chemistry, practical prototype device design in electronics. Repetitive drawing of the film leads to high rate orientation processing such as zone refining in semiconductor processing. The same concept can be applicable to side chain fluorescent molecular polymer systems for high performance optically active waveguide devices.

Soliton generating polymer film waveguide was also deigned and solitonizaton of femto second light pulse of mode-locked Ti:Sapphire laser was observed in only a few millimeter guide length of DR1 side chain PMMA film waveguide. Theoretical calculation of the guided wave behavior is shown in Fig 6(a). In this picture



(a) calculated propagation of soliton wave



(b) observed soliton

Fig.6 (a)Calculated propagation of soliton wave in NLO waveguide and (b)observed soliton by correlation method.

reshaping of the waveform is confirmed. Usual soliton generating system in single mode silica fiber request much longer fiber line and very high stability of the system in comparison with our compact high performance nonlinear optical thin film waveguide device.

5. Concluding remarks

Concept of bound electron photonics in organic materials opens new research and application fields against semiconductor science. Practical utilization of GIPOF system and its surrounding key devices can drive and proceed the concept.

References

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