Introduction On Organic Nonlinear Optical Materials

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Abstract

Organic materials are important materials for the fast processing of information and for optical storage applications. This paper tries to have a quick look at their properties and some effects.

1. Introduction

Recent developments in the field of nonlinear optics(NLO) has pushing organic second-order nonlinear optical materials into practical applications. Nonlinear optical materials are the materials in which light waves can interact with each other[1]. This paper presents an brief introduction on the organ nonlinear optical materials.

2.Molecular Polarizabilities

The following equation describe the normal nonlinear optical effects:

$$P_i = P_{0,i} + \varepsilon_0(\chi_{ij}^{(1)} E_j + \chi_{ijk}^{(2)} E_j E_k + \chi_{ijkl}^{(3)} E_j E_k E_l +$$

P_0 is the spontaneous polarization and $\chi^{(n)}$ is the nth order susceptibility tensor. ε_0Is the vacuum permittivity. E is the applied electric field.

In organic materials the optical properties are determined by the molecular polarizabilities. The following equation expressing the molecular dipole moment p as:

$$p_i = \mu_{g,i} + \varepsilon_0 (\alpha_{ij} E_j + \beta_{ijk} E_j E_k + \gamma_{ijkl} E_j E_k E_l$$

where $\mu_{g,i}$ is the ground state dipole moment, α_{ij} is the linear polarizability, β_{ijk} is the second-order polarizability or first-order hyperpolarizability, γ_{ijkl} is the third-order polarizability or second-order hyperpolarizability. The electric field is the one at the location of the molecule.

Fig1 shows the different of optical effects between first and second order nonlinear optical materials[1].

Fig1 First and Second Order nonlinear optical effects

Pure first order nonlinear optical effects are in the left and the pure second order effects are in the right hand side. The middle column shows the effects related to both types of nonlinearity:the photorefractive effect and the cascaded optical Kerr effect.

The tensors $\chi^{(2)}_{ijk}$ and β_{ijk} describe the second-order nonlinear optical and electro-optic effects. They are third rank tensors, in the electric dipole approximation, contain nonvanishing elements only for noncentrosymmetric molecular and crystalline structures, respectively. Third order nonlinear optical effects are described by the tensors $\chi^{(3)}_{ijkl}$ and γ_{ijkl}. No symmetry requirements are imposted on these effects to occur[2].

3 Organic Nonlinear Optical Effects

3.1 Bonding Properties of Atoms In The Molecule

We assume that the molecules function independently of each other and only their net orientations within the crystal lattice are important to the contribution of model.

The bonding with the carbon atom and other elements has two types: σ bond and π bond. σ bond is confined along the inter-nuclear axis of the carbon -carbon bond. And π bonds are regions of delocalized electronic charge distribution above and below the inter-atomic axis(Fig2) [3]

Fig2 Electronic bonding in (a) H_2 (σ bond) and (b) C_2 (π bond)

3.2 Why Organic Can Has NLO Properties

The polarizability of organic materials is generally the contribution from the lattice components(atoms,molecules) because of the weak intermolecular bonding(Van der Waals, dipole-dipole interactions, hydrogen bonds). Non-linear optical effects of molecular crystals depend on the polarizability of the electrons in the π bonding orbitals.

The optical nonlinearity can be increased if you add conjugated bonds(increasing L–The length of the conjugated system) or substitute donors(can donate electrons into the π electron system) and acceptors(can accept electrons into the π electron system)(Fig3). The addition of the functionality at the ends of the π system can enhance the asymmetric electronic distribution. [4]

Fig 3 organic materials for nonlinear optical effects of second-order. D-Donor A-Acceptor . substituted molecules with π electron ring systems. (i) one ring systems (ii) two ring systems

Studies show that conjugated organic molecules with large delocalized π electron systems have very large nonlinear optical effects. The attachment of functional groups with electron-accepting and donating character at opposite ends of the conjugation bridge leads to an essentially one-dimensional charge transfer, enhancing especially the second order non-linearity[1].

A further simplified model (the Equivalent Internal Field, EIF model) of a free electron gas corresponding to the delocalized π electron density of a conjugated approximation $\beta \sim \mathrm{L}^3$,which shows the strong nonlinear dependence of the hyperpolarizability on the lenth of the conjugated π system.

3.3 Organic Nonlinear Optical and Electro-Optic Effects

The Fig 4 is the schematic representation of important nonlinear optical and electro-optic effects[1]. Let us discuss the first five effects briefly.

Fig4 Important nonlinear optical and electro-optic effects

3.3.1 Sum Frequency Generation

Sum frequency generation is the mixing of two incident light waves of frequencies ω_1 and ω_2 creating a wave of ω_3=ω_1+ω_2.

3.3.2 Second-Hrmonic Generation(SHG)

Second-harmonic generation(SHG) or optical frequency doubling is just a special case of sum frequency generation. Only one light wave of frequency ω is incident, generating a wave of twice the frequency.

Sum frequency and second-harmonic generation are standard techniques to create a new coherent output from existing laser systems and especially to access the short wavelength range towards the ultraviolet region.

3.3.3 Difference Frequency Generation

Difference frequency generation(DFG) is treated as the interaction of two input beams of frequencies ω_3 and ω_1 resulting in an optical field with the frequency ω_2=ω_3-ω_1.

Because of the Conservation of Energy and Momentum, all the nonlinear processes discussed have in common that they conserve energy, which was already implicitly assumed: ω_3=ω_1+ω_2

3.3.4 Optic Parametric Oscillation/Generation

Optic parametric generation is a special case of difference frequency generation, where only the pump beam is incident on the nonlinear material generating two beams at the frequencies ω_1 and ω_2.

In order to enhance the efficiency of either process, the nonlinear medium can be placed inside a cavity with highly reflecting mirrors for the frequencies ω_1 and/or ω_2.

4. Conclusion:

The organic materials exhibit extremely large nonlinear optical and electro-optic effects. The electronic nonlinearities are essentially based on the molecular units. Due to the important advantages of the organic materials, they will be widely used in the field of organic chemistry, materials science, physics and electrical engineering.

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