# *Introduction to Nonlinear Optics*

Nonlinear optics (NLO) is study of nonlinear relationship between action and reaction (response) of objects under strong interaction.

## 1.1 Importance of Nonlinear Optics

As is well-known, the modern physics was found on two headstones of the quantum physics and the relativity physics in the early 20th century.

*The quantum physics* studies the movement theory of microscopic particles including molecules, atoms, nucleons and elemental particles.

### 1.1.2 Status of Nonlinear Optics in Modern Optics

Since the invention of laser in 1960, the modern optics was born. We call the optics based on the common light source with the spontaneous radiation as *traditional optics*; and the optics based on the laser source with the stimulated radiation as *modern optics* (we can call it as *Photonics)*.

Table 1

| Subdisciplines | Research object | Main application |
|---|---|---|
| *Nonlinear optics* | Interaction between laser and matter | optical storage, slow light, high resolution spectrum analyze, and digital optical information processing |
| Fourier optics | | |
| Guided wave optics | | |
| Quantum optics | | |

## 1.2 Wave Equation for Nonlinear Medium

$$\nabla^2 E - \frac{n_0^2}{c^2}\frac{\partial^2 E}{\partial t^2} = \frac{1}{\varepsilon_0 c^2}\frac{\partial^2 P}{\partial t^2},$$

## 1.3 Parameters of Medium are Function of Optical Field

$$P = \varepsilon_o \chi^{(1)} E + \varepsilon_o \chi^{(3)} |E|^2 E = \varepsilon_0 (\chi^{(1)} + \Delta\chi^{(1)}) E,$$

$\Delta\chi^{(1)}$ is the variation quantity of first-order susceptibility induced by the electrical field of impressed light, which is proportional to the square of light field amplitude, i.e., the light intensity **I**.

Because the third-order nonlinear susceptibility $\chi^{(3)}$ is a complex number, it can be written to real and imaginary parts:

$$\chi^{(3)} = \mathrm{Re}\ (\chi^{(3)}) + \mathrm{Im}\ (\chi^{(3)}).$$

$$n = n_0 + \Delta n,$$

$$\alpha = \alpha_0 + \Delta\alpha,$$

where $n_0$ is the linear reflective index; $\Delta n$ is the nonlinear reflective index; $\alpha_0$ is the linear absorption coefficient; $\Delta\alpha$ is the nonlinear absorption coefficient.

$$\Delta n \propto \mathrm{Re}\ (\chi^{(3)}) I,$$

$$\Delta \alpha \propto \mathrm{Im}\ (\chi^{(3)}) I.$$

## 1.4 Research Content of Nonlinear Optics

### 1. Optical Kerr Effect

When a laser beam passes through a medium, the refractive index of the medium will be changed. The variation quantity is proportional to the light intensity, that is

$$n = n_0 + n_2 I,$$

where $n_0$ is the linear refractive index of medium, I is light intensity in medium, $n_2$ is the nonlinear refraction coefficient.

### 3. Nonlinear absorption

In the condition of resonance interaction between laser and medium, the absorption coefficient of medium a can be changed with increase of light intensity until saturation. The absorption-coefficient change is different for different material.

**Raman scattering**