

Engineering Applications of Nonlinear Optics

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Introduction

In the early 1980s nonlinear optical materials was extended with a new production of semiconductor materials. For example, multi-quantum well is produced by the amplification of two different semiconductor layers (GaAs and AlGaAs). That let the formation of consecutive hills and valleys of variable potential, for electrons and holes. It is regarded that the carriers are within these potential walls. Hence, they display a semi two-dimensional behavior and large optical nonlinearity.

It can be an useful instrument for network communication for Photonic information and communication systems. It has developed very fast in last years. However, using only fiber optical systems has not ability to meet the necessity on carrying the information flow in future of communication systems. Fast optical switches which can verify (process) large scale of data should be developed so as to remove the gateways caused by optoelectronic return throughout the network. Large and fast nonlinear optical (NLO) materials are appropriate tool for photo-dynamic therapy to treat serious diseases like cancer, and other biomedical applications in the near future soon (L. W. Tutt et al., 1993) for optic controller, optic correction and optic power limiting practices (T. D. Mody et al., 2001) (Wung, C. J. et al., 1993).

Some of the advances in science and technology is crucial for the development of third-order non-linear optical materials are summarized below:

Theoretical Modeling: To increase the magnitude, especially for third-order nonlinearities, predictive capabilities need to be improved. Progress at this point might enable the prediction of polymer structural and other functionalization requirements that may be necessary.

Molecular Engineering through Polymer Design and Chemical Synthesis: Progress in sythetic and polymer chemistry and chemical engineering is significant for sustainable progress in producing systematically varied structures where the impact of important electronic or structural features can be studied. The rigorous processing requirements should be on center of synthetic strategies associated with waveguide fabrication and performance issues. Examples of such issues are control of domain structures that can lead to refractive index in homogeneities, environmental stability, photo stability, mechanical compatibility with substrates, and adhesion (Artkin F., 2014).

Material Processing: Processing conditions are vital in figuring the ultimate quality of fibers and films of organic and polymeric materials. One promising avenue for optimization of electronic properties, meanwhile the variety of needed ancillary

properties, is done by of polymer blends and composites. To show a sample of this approach is a current improvement of a composite between sol-gel processed silica and polyparaphenylene vinylene (Sutherland, R. L. 2003). This silica gel is an excellent linear optical medium with extremely low optical losses, yet it has rather low third-order nonlinear coefficient. Special processing techniques has been improved to eradicate general tendency for phase separation which occurs at higher concentrations of polymer. The resulting films have excellent optical quality and a nonlinear coefficient is consistent with the polymer intensity in the glassy medium. Device Structures: There are considerable opportunities in the process of development and production of device structures. A number of preliminary device structures have been found out, as properties of materials are improved and their intrinsic advantages and limitations realized, refinements in devices which can be benignant in terms of their advantages will undoubtedly be pursued (B. G. Maiya et al., 1989).

Nowadays, characterization is particularly important for materials showing suitable properties for nonlinear optical devices. Various techniques are applicable for these materials' characterization. In this study, Z-Scan technique is used which provides advantages in many aspects.

Methods for Studying of Optical Nonlinearity of Engineering Applications

It is highly popular nowadays to find materials with large but fast non-linear properties, database enlargement becomes necessary. Methods for determining non-linear parameters are discussed throughout this book chapter, search which creates curiosity, for materials purely optical controlling and detector protection ingredients, it's about nonlinear absorption (NLA) and nonlinear refraction (NLR). Database for optic features matters, especially natural, some situations are not sufficient for metric determination to guide synthesis efforts.

Degenerate Four Wave Mixing (DFWM): Operated for measuring third order non-linear reaction and magnitude this reaction.

Third Harmonic Generation: Used only for measuring third order nonlinearity.

Electro-absorption technique: Third order nonlinearity dispersion, this technique is applied.

Time-Resolved Optical Kerr Effect and Transient Absorption Techniques: Used presenting photophysical processes that determine nonlinearity.

Z-Scan: Used for measuring magnitude of third order nonlinearity and its sign.

In this regard, the reader should be aware that the results for using the z-scan method, active non-linear processes of any reference are frequently a matter of debate. The Z-scan technique is a type of method that quickly measures both NLA and NLR in solids, liquids and liquid solutions. The non-linear optics community has swiftly adopted the Z-scan approach as a standard method for identifying Non-linear variations in index and absorption must be considered independently. It should be emphasized, however, that

the approach is susceptible to any non-linear optical phenomena that cause variations in the refractive index and absorption coefficient, making it difficult, in most cases, to infer the underlying physical mechanisms from a Z-scan (Paras N. Prasad et al., 1991).

Degenerate Four Wave Mixing (DFWM)

A physical description degenerate four-wave mixture, principle, treated similarly to harmonic generation (or frequency mixing), except for three spatially distinguishable field waves in this process, except for $E_1(\omega, t)$, $E_2(\omega, t)$, $E_3(\omega, t)$ interacts with the same frequency (ω), creating the fourth wave $E_4(\omega, t)$ in the same order, but with a different propagation direction.

Figure 1. can be solved under the assumption of slowly varying amplitude approximation, which assumes that it wave density variation throughout the propagation distance negligible on scale of wavelength of light, and negligible pump beam depletion to obtain the expression for field E_4 as a function of propagation distance z in non-linear media.

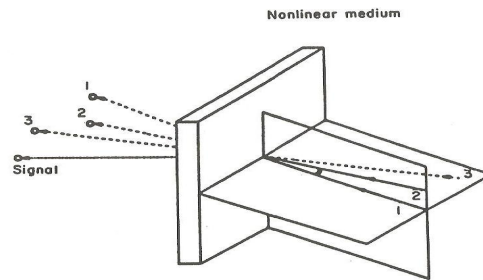


Figure 1. Four beams are available in scheme in the forward-wave arrangements for degenerate four-wave mixing.

As in the example of harmonic generation, the wave equation also yields the requirement to match phases $k_1 + k_2 + k_3 + k_4 = 0$.

Many different beam geometries have been used for degenerate four-wave mixing (DFWM). The two common geometries are shown in Figures 1. and 2. The Figure 1 shows the forward wave geometry arrangement with all incident beams (E_1 , E_2 , and E_3) are propagating from right to left by following the same way. It also shows the phase-matched direction of the output beam (signal) E_4 . Figure 2. shows a backward-wave geometry in which two beams E_1 and E_2 , called the forward and reverse beams E_f and E_b , are counterpropagating and third beam E_3 , also called the probe beam E_p . The process of DFWM synonymous with optical phase conjugation in backwave geometry (Fisher, R.A., 1983). From this perspective, it is considered the interaction of two counterpropagating pump beams I_f and I_b , which set up a phase conjugate mirror. A probe beam I_p incident on it is reflected to retrace itself. However, it can swap energy with the other beams. I_s is used to refer the conjugate of the probe beam I_p . Therefore, any phase distortion suffered by the probe beam I_p is reconstructed in beam I_s . The process is utilizable for high-contrast dynamic holography.

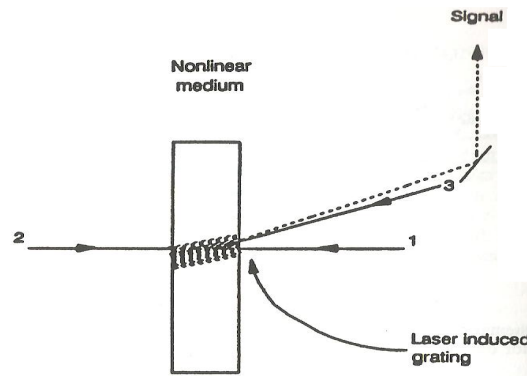


Figure 2. Schematics of the four rays in the reverse-wave arrangement degenerate four-wave mixing.

The DFWM process can also be intuitively comprehended by imagining a laser-induced grating (Eichler, H. et al., 1986). At this level, the interaction of two harmonic beams in a material causes intensity modulation. Because the refractive index of nonlinear media is intensity dependent, the refractive index modulates, resulting in a diffraction grating. If the refractive index of the medium is complicated, the refractive index's real component changing opens the way for what is known as a phase grating (Eichler, H. et al., 1986) (Fayer, M. D. et al., 1982). An amplitude grating is created when the refractive index's imagined portion modulates. In the case of reverse DFWM geometry, each rays pairings generate three separate grids, but only two of these grids yield phase-matched conjugate signals (Shen Y.R. et al., 1984).

Third Harmonic Generation (THG)

However, the it component is included in the wave equation for the propagation of a plane wave electric field in a nonlinear medium. Under low signal or low conversion conditions, the solution of the consequent connected amplitude equations. This circumstance occurs when the phase promptness of the primary and third harmonic waves is equal. However, dispersion refractive indices (which are often different) results in varying phase promptness for the main and third harmonic waves.

Therefore, for finite values of phase mismatch, decreases from its value at and undergoes damped oscillations.

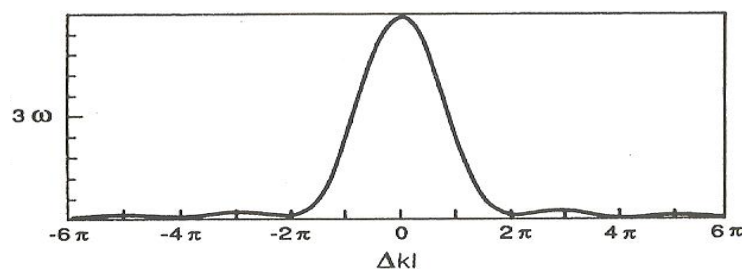


Figure 3. Third-harmonic intensity in random parts, marked as a function of l , for a finite wave-vector mismatch

Natural birefringence to phase match may be favorable in anisotropic media, such as birefringent crystals, since it is useful for efficient second-harmonic production. For instance, it is possible to choose a direction of propagation for which

$$n_e(3\omega) = n_o(\omega) \quad (1)$$

The letters e and o stand for extraordinary and ordinary rays, respectively. However, due to the significantly divergent frequency values of fundamental and third harmonic waves and inadequate birefringence, phase matching for third harmonic production in a material such as crystal is difficult to achieve in practice.

Due to dispersion effects on the refractive index, phase matching cannot be met in pure isotropic media such as gases, liquids, or amorphous polymers. However, phase matching may be achieved in theory by mixing two isotropic media A and B (acting same two gases) (Shen, Y.R. et al., 1984).

$$n_A(\omega) + n_B(\omega) = n_A(3\omega) + n_B(3\omega) \quad (2)$$

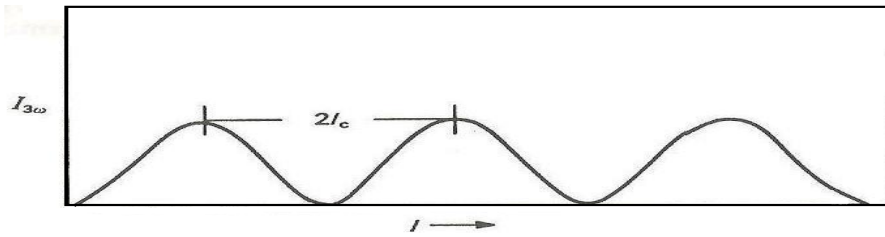


Figure 4. Wedge fringe pattern for third-harmonic signal obtained as a sample is translated to change the path length l .

When the interaction length is changed, the oscillatory behavior of is described by a fringing curve. In the case of a wedge-shaped sample, the change of interaction length by translation of the sample produces a wedge fringe pattern, demonstrated in Figure 4.

Harmonic generation (or frequency mixing in general) is a coherent process by taking account the perspective out wave generated at the new frequency has a definite relationship with the phase of the input waves. It is derived from non-linear interactions that appear instantaneously. Such consistent non-linear states are only obtained from electronic interactions that have no dependence on the excited state population. We shall see later that dynamic nonlinearities that involve electronic or molecular excitations are incoherent non-linear responses of a medium and depend on the population density of excitation in the medium.

Electric Field-Induced Second-Harmonic Generation (EFISH)

It has contributions both from second- and third-order nonlinearities. However, for centrosymmetric structures or structures with small second-order nonlinearity, the EFISH generation is derived from the third-order susceptibility, γ . The EFISH process can be depicted as unusual example of four-wave mixing where one area is in bottom in terms of frequency or dc-electric area for which crosschecked with optical field's sequence. Thus it can be regarded, a particular situation of sum-frequency generation.

For rigid solid structures where alignment of molecular bipolarity corresponding with the electric field is energetically improbable, the EFISH process is derived from γ even though the molecular structure might permit a large. This is the case with isotropic polymers below their glass transition temperatures. As for third-harmonic generation, the EFISH process probes only purely electronic third-order nonlinearity, which has an instantaneous response (Paras N. Prasad et al., 1991).

Z-Scan Technique

A z-scan measurement is operated in nonlinear optics to estimate the nonlinear index n_2 Kerr nonlinearity and nonlinear absorption coefficient using open and closed approaches, respectively. Because non-linear absorption might alter the measurement of the non-linear index, the explicit approach frequently operated to rectify computed value of the implicit technique.

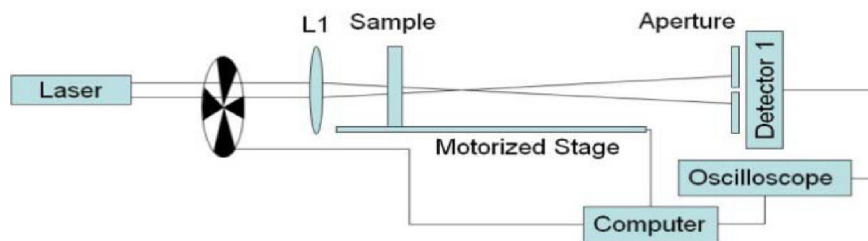


Figure 5. Experimental Z-scan setup.

An aperture is constructed in this experimental configuration to prevent part light from passing through detector is set up as shown in the diagram. A laser is focused by a lens. Some extent before the beam naturally drifts out of focus. An aperture detector is placed behind it after a considerable distance. The aperture allows just light cone's field center to reach the detector. It is frequently within the normalized permeability range

$$0,1 < S < 0,5 \quad (3)$$

The detector is sensitive to any focussing or defocusing caused by the sample. Sample is normally positioned at the focal point of lens and then passed across the z axis, the distance between which is provided by the Rayleigh length z_0 ;

$$z_0 = \frac{\pi W_0^2}{\lambda} \quad (4)$$

According to the thin sample approximation, sample L' density must be less than Rayleigh length $L < z_0$.

Z-Scan Measurements

Definition: A method for determining the strength of Kerr nonlinearity in a material that relies on self-focusing.

The z-scan measuring technique (M. Sheik-Bahae et al., 1989) (M. Sheik-Bahae et al et al., 1990) is frequently used to calculate an optical material's kerr nonlinearity force (ie the magnitude of the non-linear index n_2). To demonstrate the functional location of the sample, A sample of the material under investigation is moved along the laser beam's focus, and the beam radius (or on-axis intensity) is measured at one point while holding it behind the focus zone. These figures are influenced by the self-focus effect. If the non-linear index is positive and the sample is positioned below the focus, self-focusing reduces beam deflection and hence increases detector signal (as shown in Figure 5). When the sample is moved to the left of the focal point, the focus shifts to the left and the detector signal decreases. The observed reliance of the detector signal on the sample position may be used to calculate the magnitude of the non-linear index. Non-linear absorption, such as two-photon absorption, can also have an effect on the measured signal. This, however, may be monitored individually while keeping the power of the total transmitted beam constant. Nonlinearity measurements can be adjusted using these data.

Advantages and Disadvantages of Z-Scan Technique

Advantages:

- There are no complicated situations except focusing the beam on the slit Magnitude and sign of nonlinearity can be measured simultaneously.
- Refractivity and absorptivity parts of nonlinearity can be isolated. Yet, employing DFWM technique cannot be helpful.
- Except for a few exceptions, data analysis is quick and easy.
- Intensity is high. If sample has high optical quality, even a phase distortion of $\lambda/300$ can easily be decomposed.
- A close similarity exists between Z-scan and geometry that limits optical power.

Disadvantages:

- The requirement for a high quality Gaussian TEM00 beam for several experiments is a drawback because to the difficulty in obtaining it.
- Analysis is completely different for non-Gaussian beams.
- Beam is infractible because of irregularities of the sample.

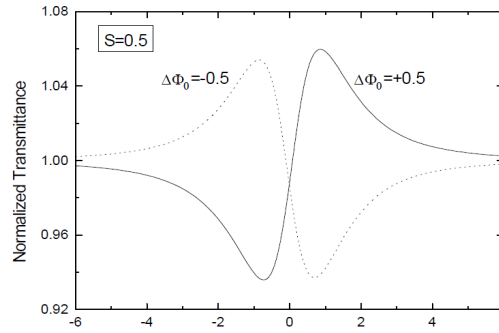


Figure 6. Typical Z-scan for positive data (solid line) and negative (dashed line) data nonlinear refraction of third order.

A typical closed aperture Z-scan result for a thin sample with non-linear refraction is shown in Figure (6). (solid line). As the example moves away from the lens, a self-focusing nonlinearity, $n > 0$, generates a peak followed by a trough in normalized transmittance (increasing Z).

One of the enticing aspects of the Z-scan technique is the ease and simplicity with which non-linear optical coefficients may be created with approximate accuracy.

However, as is the case with the vast majority of non-linear optical measurement techniques. The accurate estimate of nonlinear coefficients, such as n_2 or, is hence dependent on competing nonlinearities. It becomes critical as reliance on the temporal and spatial profiles of the laser source, power or energy content, as well as stability Z scan may be thoroughly modeled for every beam form and sample thickness by solving the appropriate Maxwell equations under certain nonlinearity conditions (for example, a very rapid (3) response). Many appropriate assumptions and forecasts, on the other hand, will result in simple analytical expressions and make data analysis easy yet exact. Outside of the usual SVEA (slow changing envelope approximation), neither diffraction nor non-linear refraction within the non-linear sample will alter the beam profile, as long as the non-linear sample is narrow.

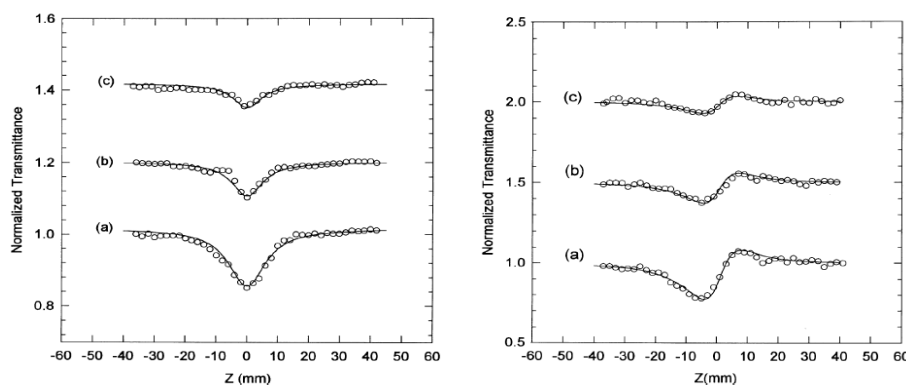


Figure 7. Z-scan measurements for various laser intensities on lithium niobate (Heping Li et al., 1997): (a) 22 GW/cm², (b) 12 GW/cm², (c) 6 GW/cm² experimental data (circles) and theoretical fits (straight lines). Left: non-linear absorption through open aperture geometry; right: non-linear refraction via closed aperture geometry. For graphing, the downs for (b) and (c) have been adjusted vertically.

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To Cite This Chapter:

Artkin F., (2022). Engineering Applications of Nonlinear Optics Learning. In S. Kocer, O. Dundar (Eds.), *Current Studies in Basic Sciences Engineering and Technology* (pp. 82–91). ISRES Publishing.