A NONLINEAR PHASE SHIFTS IN QUADRATIC MEDIA WITH SELF-FOCUSING AND SELF-DEFOCUSING OF FEMTOSECOND PULSES

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ABSTRACT

It is possible to imprint nonlinear phase shifts on pulses propagating via quadratic nonlinear mediums. Phase shifts of femtoseconds are discussed in this article, and their applications to femtosecond pulse production and propagation are also discussed. Ultrashort pulses can only be imprinted with self-defocusing nonlinear phase shifts in quadratic media. Pulses with a length of a few optical cycles will be introduced as part of ongoing research on controllable nonlinear phase shifts. Nonlinear phase is examined in this research, as well as an analytical investigation. Self-focus and self-defocus are topics of our research. Additionally, this paper introduced a Cascaded Quadratic Nonlinearity for Femtosecond Pulses. We looked at nonlinear phase and quadratic media in this work. Femtosecond pulses are investigated in this article with a cascaded quadratic non-linearity. Supporting the production of optical spatiotemporal solitons is the cascaded quadratic nonlinearity.Cascaded quadratic nonlinearity refers to the fact that it involves sequential or cascaded quadratic processes which are explained in this study.

Keywords: Nonlinear Phase, Quadratic Media, self-focusing, self-defocusing, Femtosecond Pulses

1. NONLINEAR PHASE SHIFTS IN QUADRATIC MEDIA

Frequency conversion is a common use for quadratic optical nonlinearities. However, it has long been known that nonlinear phase shifts may be generated by the interactions of light beams in quadratic nonlinear media. Nonlinear phase shifts in quadratic systems were studied in isolation between 1970 and 1990, and there has been a recent boom in this field. Any 3-wave mixing procedure can create nonlinear phase changes. Phase-mismatched second harmonic generation (SHG) is the simplest scenario in which the fundamental field obtains a nonlinear phase shift during the conversion to the second harmonic field and back conversion to the fundamental field (Fig. 1). Our primary focus here will be on the basic field's nonlinear phase shift. Cascaded quadratic nonlinearity refers to the fact that it involves sequential or cascaded quadratic processes. The following are the characteristics of this phase shift:

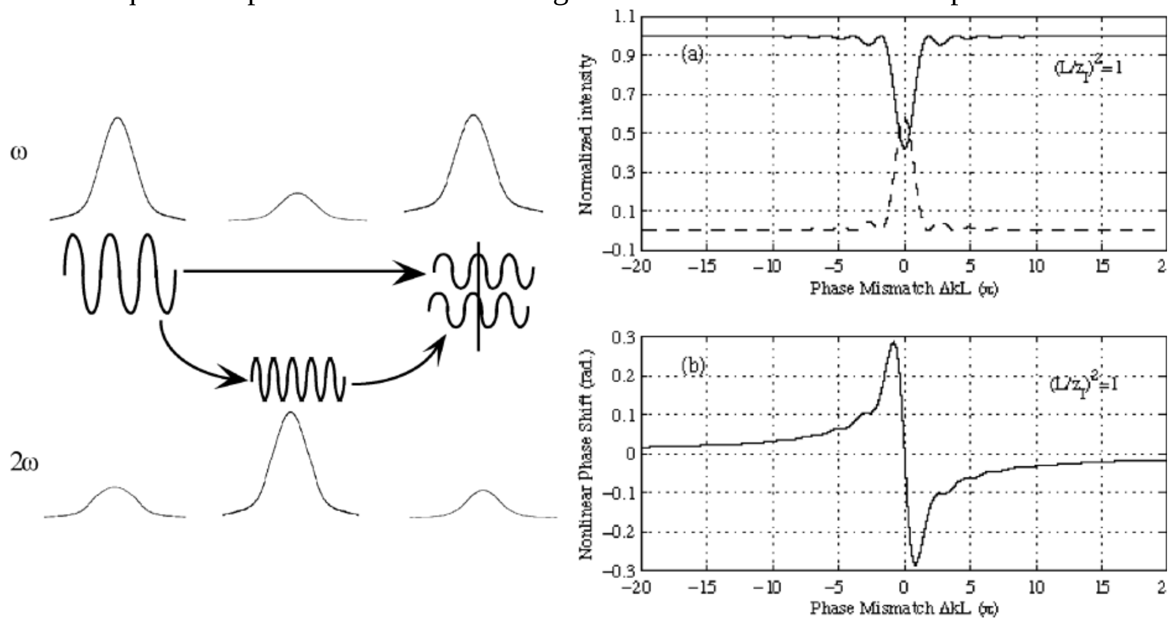

Fig. 1 Left panel: Origin of the cascaded quadratic phase shift. Some of the fundamental ield undergoes one or more cycles of conversion and back-conversion. When the energy

is in the second-harmonic field, it propagates with the phase velocity of the second-harmonic frequency, so when it returns to the fundamental frequency it is out of phase with light that was not converted. The resulting phase shift depends on the phase-velocity mismatch and the intensity of the input fundamental field. Right panel, top: Normalized peak intensities of the fundamental (solid) and second-harmonic (dashed) fields. Bottom: nonlinear phase shift onthe fundamental field

- It's possible that it'll be enormous (around 10 radians in actuality).
- The wave-vector mismatch (Fig. 1) may be used to regulate the nonlinearity's sign; it can be self-focusing or self-defocused.
- The wave-vector mismatch can be used to modulate its magnitude (Fig. 1) With increasing intensity, the magnitude saturates.

There is a straightforward proportionality in phase shifts when wave-vector mismatches are big

$$\Delta\phi_{NL} \propto \frac{d_{eff}^2 IL}{\Delta k} \qquad (1.1)$$

k is the wave-vector mismatch, and d_{eff} is the total of all relevant components of the quadratic nonlinear susceptibility.

A crystal's orientation or temperature can be used to modify the wavevector mismatch and hence the cascaded quadratic phase shifts. The most innovative new possibilities for pulse-shaping are likely to be enabled by the capacity to alter the sign of the nonlinear phase shift, and in particular by the ability to produce negative phase shifts without severe loss. The research on self-focused nonlinear systems is evident in this book, but little research has been done on self-defocused nonlinear processes. There are substantial pulse shaping applications to be found in the cascaded quadratic nonlinearity when either self-defocusing or self-focusing nonlinearities are used.

When a significant portion of the total energy is converted to the second harmonic field in a single conversion-back-conversion cycle, the cascaded quadratic nonlinearity becomes saturated. Since nonlinear phase shifts in cubic media are inversely proportional to intensity, saturation in nonlinear media affects the temporal fluctuation of the phase shift (and hence the frequency chirp). To prevent the collapse of multi-dimensional solitons in cubic nonlinear media, saturation is essential. We'll go into this in more detail in a moment.

N_2 is a nonlinear index of refraction derived from the cubic nonlinearity, $x^{(3)}$. It is possible to establish an effective nonlinear index for the cascaded quadratic process below saturation, where the nonlinear phase shift is proportional to the fundamental field strength. A 2-photon absorption may be compared to residual second-harmonic light created in the phase-mismatched process by using the analogy of cubic nonlinear processes.

1.1 Self-FocusingVersusSelf-Defocusing

Of course, the cubic nonlinearity found in all materials contributes to the net phase shift imposed on a pulse, which is normally positive. As a result, we may consider processes 2 and 3 to be a part of an overall effective n2. An example of a typical quadratic substance is shown in Figure 2. In order to bias the overall nonlinear index, the actual n2 due to 3 has a minimal dependence on crystal orientation and temperature. Multiple self-focusing and self-defocusing zones are possible as a consequence. When cubic phase shifts are positive, self-defocusing is only conceivable on one side of k 0 in the usual scenario. As we'll see in the following section, this finding is particularly relevant when other factors limit the size of k in a specific application.

1.2 AnalyticalFramework

This article's definitions and equations for the cascaded quadratic process may be found below for your convenience. Gaussian units are employed. – In most cases, these particulars are superfluous to understanding the primary points of the text.

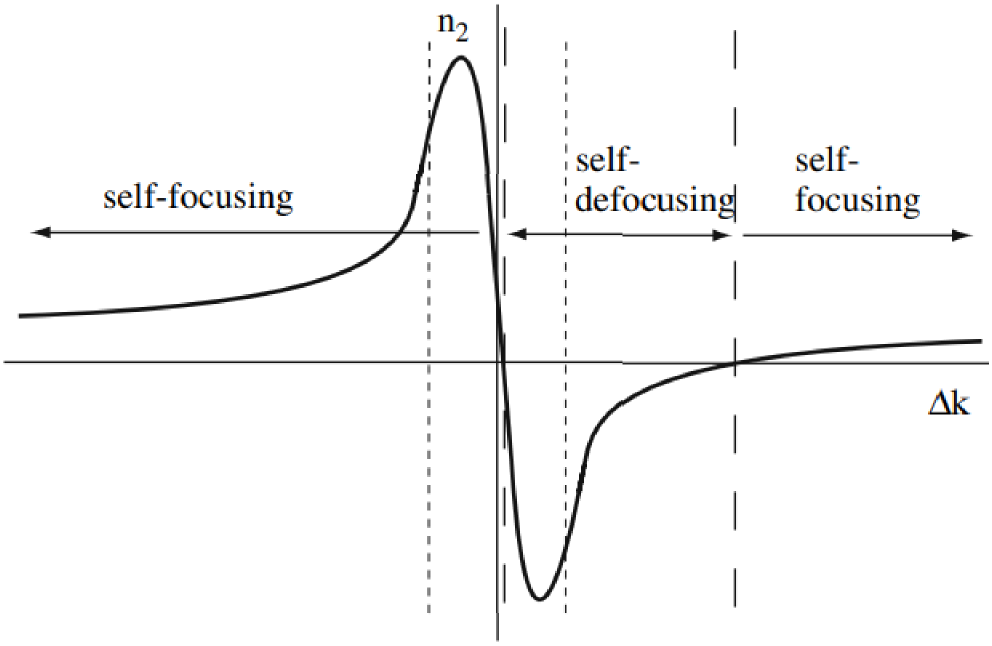

Fig. 2 The total effective n_2 resulting from both quadratic and cubic contributions plotted versus $\Delta k$for the typical case when $X^{(3)}$phase shifts are positive. Self-focusing and selfdefocusing regions are indicated. The short-dashed lines represent a possible location of the stationary boundaries.

2. ULTRASHORT PULSE SHAPING

Interaction between linear and nonlinear phase accumulations governs the propagation of a light pulse in a transparent material. The linear phases of diffraction and GVD are entangled in the limits of monochromatic and planar waves, respectively. A laser beam's transverse spatial profile changes as a result of diffraction. As long as self-focusing and diffraction are perfectly balanced, the outcome is a spatial soliton—a beam that does not spread laterally. spatial solitons are stable in one transverse dimension in cubic nonlinear media and unstable in the other two dimensions.

The creation and transmission of powerful ultrashort laser pulses (picosecond and femtosecond) is dominated by phase modulation. The positive (or self-focusing) nonlinear phase shift that is imposed on a pulse by the process of self-phase modulation (SPM) is balanced by that which results from abnormal GVD as an example of temporal soliton creation In the absence of (linear or nonlinear) absorption, all materials have cubic nonlinearities, which are virtually invariably self-focusing, n2>0. Prism pairs, grating pairs, or chirped mirrors are commonly used to create anomalous GVD in materials with or without absorption. Modern femtosecond lasers, pulse compressors, and related technologies all use soliton-like pulse shaping.

Even if the nonlinear Schrodinger equation, which regulates the propagation of plane-wave pulses in cubic nonlinear media, has the nonlinearity and dispersion signs reversed, the same soliton will still emerge. Because of this, soliton-like pulse shaping may be achieved with a normal GVD in medium with rapid negative (self-defocused) nonlinear refraction. Transparent materials can be used instead of the traditional prism or grating pairs to construct lasers and other devices. This can lead to significant improvements in both speed and efficiency. For a long time, no attempt has been made to find media with self-defocusing nonlinearities (n20) and minimal loss.

Extremely large nonlinear phase shifts are common in the development of high-energy pulses, yet they're necessary to make ultrashort pulses. Fiber lasers and amplifiers and ordinary bulkoptics devices are affected by these at the nanojoule and microjoule levels, respectively. They appear as self-focusing and instability in the beam profile, both of which have a deleterious effect on the beam's properties in the spatial domain. Temporally, non-linear phase shifts cause excessive spectral bandwidth and phase distortions, which impair pulse quality or possibly destroy the pulse via optical wave-breaking.

3. EXTENSION OF THE CASCADED QUADRATIC NONLINEARITY TO FEMTOSECOND PULSES

In spite of its amazing features, the use of cascaded quadratic phase shifts for short-pulse generation was once thought to be impossible. Nonlinear optics with ultrashort pulses need group-velocity matching in addition to phase matching for optimal efficiency. As seen in Figure 3, the fundamental and second harmonic pulses are moving away from one another in time due to their distinct group velocities. The fundamental and harmonic pulses move apart by around one pulse duration over the distance defined by the group-velocity mismatch (GVM) length L_{GVM}, which we use to measure this problem. Reduces the nonlinear phase shift and distorts the nonlinear phase's temporal fluctuation across the pulse when GVM is used Barium metaborate (BBO) is nonlinear crystal with a nonlinear L_{GVM} of 0.06 mm. In quadratic nonlinear optics using femtosecond pulses, this is a typical condition.

Liu and Qian came up with a simple solution to GVM's difficulties. Conversion and back-conversion cycles cause a quadratic phase change. If these cycles can be set up to occur before the pulses split in space (i.e., at a shorter distance than the interval between them).

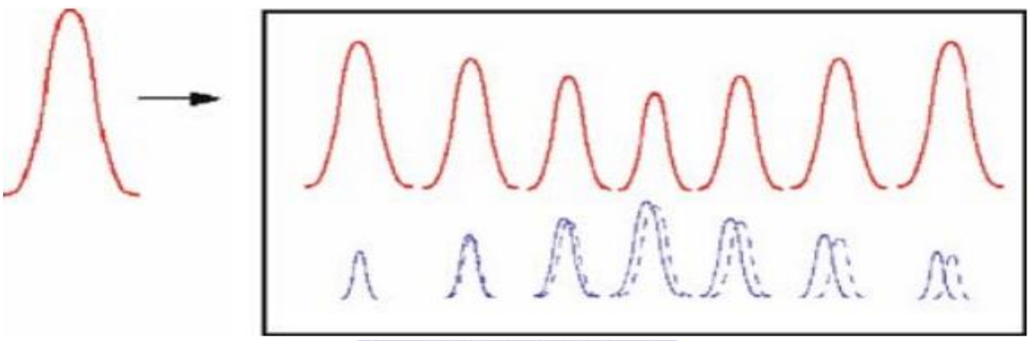

Fig. 3 Illustration of FF and SH pulses propagating in a quadratic nonlinear crystal. The dashed lines represent the propagation in the absence of GVM

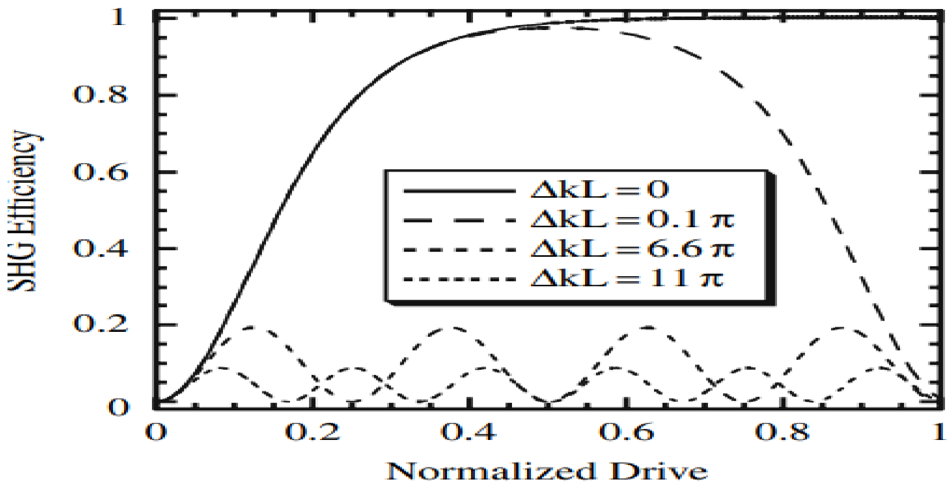

Fig. 4 SHG efficiency plotted versus nonlinear drive, which can be taken as proportional to propagation distance, for the indicated values of the phase mismatch. With larger mismatch, the conversion cycles have a smaller period, and less energy resided in the SH field

20 Self-focusing and Self-defocusing with Quadratic Nonlinearitiesthan L_{GVM}), the resulting phase shift should not suffer excessively from the GVM. This is achieved if the wave-vector mismatch$\Delta k > 4\pi/L_{GVM}$ (Fig. 4). Fig. 5 illustrates the success of this strategy. The cascaded quadratic process's instantaneous frequency (the time derivative of the nonlinear phase) is presented for various GVM and phase mismatch sizes (small and big). The frequency should follow the peak-valley pattern indicated as a dashed line to replicate the electrical Kerr nonlinearity of cubic media. (It is assumed that there is a nonlinear phase shift). As seen in the figure's bottom two rows of data, phase-shift quality improves when GVM is substantial. Before the back-conversion is finished, the FF and SH pulses in Fig. 5(e) are separated by four times the input pulse duration. Stable pulses can't be generated because of the significant distortion in the immediate frequency. It is possible to improve phase-shift quality while also decreasing the magnitude by increasing phase mismatch [Fig. 5(f)]. Cascaded quadratic phase shift usefulness ultimately depends on the nonlinearity of SHG crystals that are accessible and acceptable. It is possible for the FF and SH pulses to overlap despite their small length because of a high phase mismatch. The cascaded process's stationary limit reaches this point, and $\Delta k > 4\pi/L_{GVM}$ is called the stationary boundary. The cascaded quadratic nonlinearity mirrors the bound electronic Kerr nonlinearity in certain circumstances. For high phase mismatch, perturbation techniques approach the Schrodinger equation that controls pulse propagation in cubic nonlinear media when applied to FF. In that case, the effective nonlinearity is only the Kerr nonlinearity. We'll go into this in more detail in a moment. The creation and propagation of powerful ultrashort pulses are both affected by phase modulation. As a result of this increased flexibility, pulses may now be generated and propagated with nonlinear phase shifts of either sign that are simple, controllable, and low-loss.

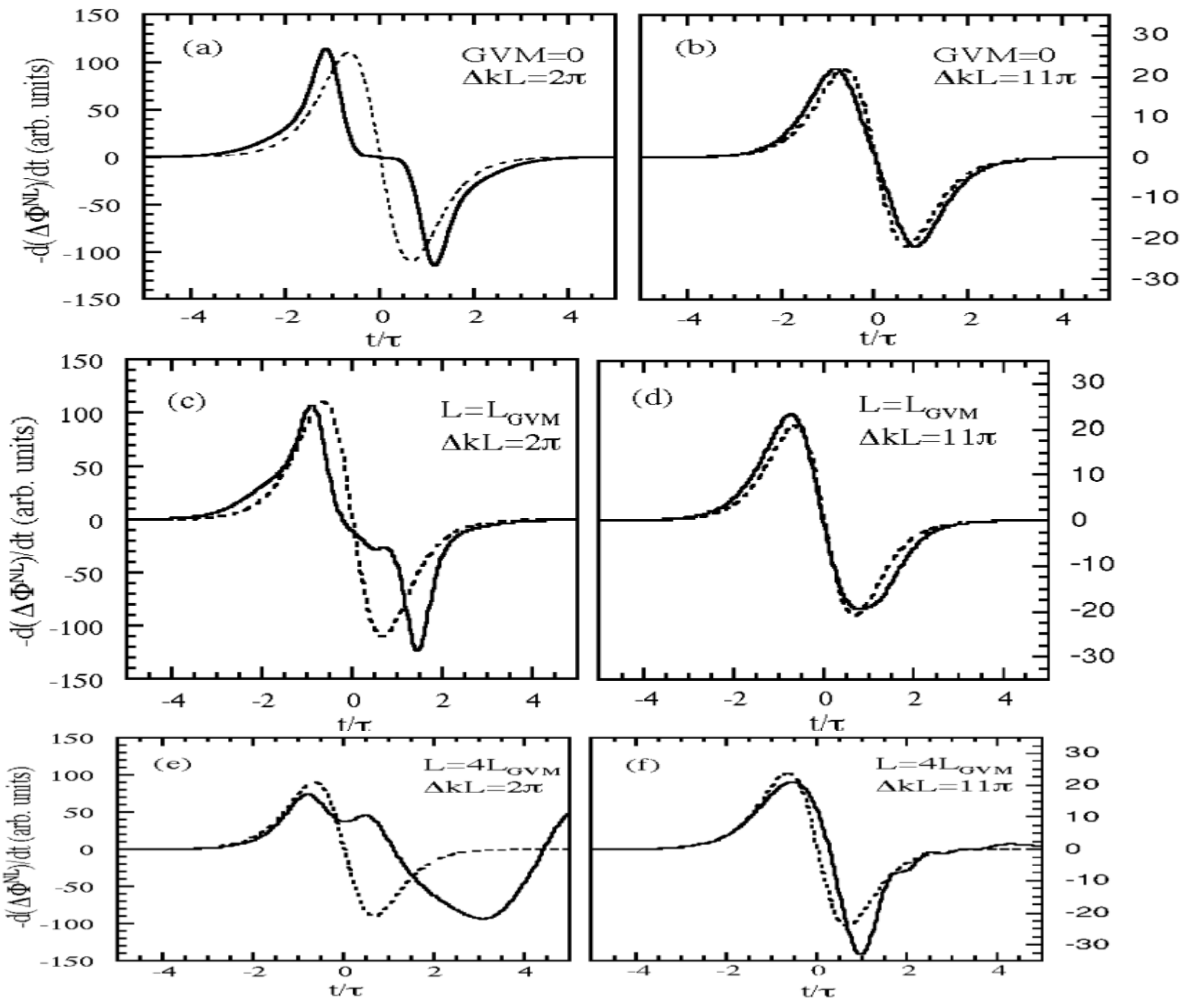

Fig. 5 Instantaneous frequency shifts of the fundamental pulse resulting from the cascaded quadratic process with the indicated values of GVM and phase mismatch. The

dashed curve in each figure represents the ideal Kerr-like shifts. The top row shows that the effects of saturation can be reduced by increasing the phase mismatch, as expected. The bottom two rows illustrate the tradeoff between magnitude and quality of the nonlinear phase shift in the presence of significant GVM pulses. In the last few years, initial applications of cascaded quadratic nonlinearities to short-pulse generation have appeared. The remainder of this paper will review some of the highlights of this effort, with an emphasis on the new capabilities that can be obtained.

4. CONCLUSION

Cascaded quadratic processes offer a wide range of novel ultrafast phenomena by controlling the sign and amount of non-linear phase changes. From fibre lasers to megawatt systems, cascaded quadratic nonlinear phase shifts have shown to be beneficial in the femtosecond time scale. Because of this cascaded quadratic nonlinearity, optical spatiotemporal solitons can be formed. New pulse propagation effects, particularly in the field of few-cycle pulses, are expected to be underpinned by the cascaded quadratic nonlinearity, according to recent research.Extremely large nonlinear phase shifts are common in the development of high-energy pulses, yet they're necessary to make ultrashort pulses. Fiber lasers and amplifiers and ordinary bulkoptics devices are affected by these at the nanojoule and microjoule levels, respectively. As a result of this increased flexibility, pulses may now be generated and propagated with nonlinear phase shifts of either sign that are simple, controllable, and low-loss.

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