Session 6

Posters:

Single-cycle Brillouin interactions of modulated light

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Since the early days of optical communications, stimulated Brillouin scatter (SBS) in optical fiber has been widely investigated due to its' dominating noise contribution, but also as a sensitive sensor of distributed temperature and strain. Despite the many years of research, SBS continues to be active area of study due to the relative ease of inducing this nonlinearity with minimal optical power, so that it is a powerful tool for studying nonlinear interactions that would otherwise require much higher power in other media. For example, recent demonstrations have utilized SBS for forming slow and superluminal light pulses. In SBS, the source of the strong dispersion is its' narrow-band gain spectrum, on the order of 50 MHz in glass fiber. In this work, we review our work with interacting intensity waves [1-3], such as suppression and quasi-phase matching of the ac components of modulated light, and report on a new means of creating superluminal and slow light by utilizing the ultra-narrow Brillouin amplifier (BA) gain spectrum.

We investigate the realm of Brillouin interaction lengths (i.e. fiber lengths) that are on the order of half the modulation wavelength. In this case, the Brillouin spectral bandwidth for the ac component is inversely proportional to the interaction length, approx. 50 kHz for a 2 km fiber. In this regime, the pump and Stokes modulation envelopes interact over less than , $\approx 1+G$ one modulation cycle. We show that the group velocity is speeded up by a factor is the Brillouin exponential gain parameter, and experimentally demonstrate a G where times faster than the linear velocity, with an optical power of 63 mW. ≈ 19 group velocity Finally, we show that when the laser is directly modulated (as opposed to external modulation), all of the SBS power, and not just the ac component, is affected by the ultra-narrow gain spectrum, leading to total suppression of the SBS power at very low modulation frequencies, and rich temporal dynamics within this narrow gain spectrum.

1. S. Sternklar and E. Granot, Opt. Lett. 28, 977 (2003)

2. E Granot, S. Sternklar, D. Kwiat and T. Arditi, Opt. Commun. 259, 328 (2006)

3. S. Sternklar, E. Granot, D. Kwiat and T. Arditi, Opt. Lett 31, 2894 (2006)

Interaction-induced localization of self-defocusing discrete solitons

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We present the first experimental study of interactions between non-collinear discrete solitons in periodic glass waveguide arrays (WGA). An important characteristic of WGAs is that normal solitons (NS), excited with a narrow input beam, are sustained over a wide range of input powers [1] (Fig. 1a). In addition, tilted beams (TB) exhibit self-focusing (SF) for input angles in the normal diffraction regime of the WGA, while exhibiting self-defocusing (SDF) in the anomalous diffraction regime (Fig. 1b). When the two beams are injected simultaneously, and their interactions are studied as a function of their relative phase difference $\Delta\theta$, the dynamics is found to be strongly dependent on the diffraction regime in which the TB is injected. With both beams at normal incidence (Fig. 2a), the results of previous experiments [2] are reproduced, *i.e.* stability for $\Delta\theta \approx (2n+1)\pi$ and attractive instability for $\Delta\theta \approx 2n\pi$. When the TB is in the SF regime, the attractive instability becomes less pronounced (Fig. 2b). In contrast, when the TB is tilted into the SDF regime (Fig. 2c), we find that the interaction extends to a wider range of $\Delta\theta$. Moreover, we find that the TB acquires a SF nature due to the interaction. The TB may then localize at any intermediate site, depending on $\Delta\theta$. We also analyze the evolution of the interacting beams numerically, in the framework of the discrete nonlinear Schrödinger equation, for diverse array parameters and excitation conditions. We find that the interaction-induced localization can indeed be reproduced by this model, for a specific range of parameters, defined in terms of the ratio of the diffraction and nonlinearity lengths, and the ratio of the excitation amplitudes of the NS and the TB.

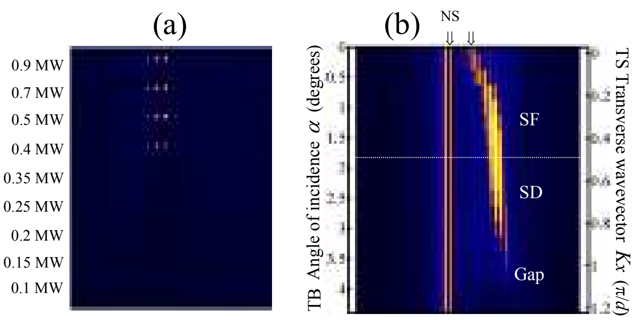

Fig. 1 (left): (a) Output facet images of the WGA for a normally injected excitation as a function of the input peak power. (b) A tilted excitation at 0.7 MW as a function of the input angle and transverse wavenumber.

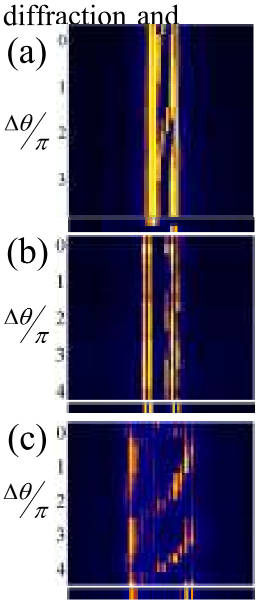

Fig. 2 (right): Output facet images of the WGA for simultaneous excitation with a normal and a tilted beam, as a function of the phase difference $\Delta\theta$. The peak power of each beam is 0.7 MW, and their separation is 2 sites. Three tilt angles are shown: (a) α=0 (normal); (b) α=0.6° (self-focusing); (c) α=3° (self-defocusing). The stripes at the bottom of each panel shows the output positions of the individual (noninteracting) excitations.

References:

[1] D. Cheskis *et al.*, Phys. Rev. Lett. **91** 223901 (2003), Y. Linzon *et al.*, Phys. Rev. E **72** 066607 (2005).

[2] J. Meier *et al.*, Phys. Rev. Lett. **93** 093903 (2004), J. Meier *et al.*, Opt. Exp. **13** 1797 (2005).

Width instability of solitons in linear lattices

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Stable lattice solitons are localized waves that propagate in optical lattices without change of their profile. We study the stability of lattice solitons in Kerr media in which the linear refractive index can have arbitrary shape, e.g., a periodic, irregular or quasicrystal structure. In this work we show that the soliton width W(b) is a more useful parameter than the propagation constant b with respect to which solitons are usually studied. Obviously, the width is the physically measurable quantity but more importantly, the width is crucial for the prediction of the soliton dynamics.

It is well known that the slope (Vakhitov-Kolokolov) condition, i.e., that $dP/db \sim dP/dW<0$, is a necessary condition for soliton stability. We show that this condition is related to the width stability of the soliton, i.e., that its violation results in large changes of the soliton width. For example, consider solitons centered at a shallow local maximum of the lattice $V = [1 + 2\cos(x) + 2\cos(y)]^2$ which can be formed experimentally by interference of plane waves, see Fig. 1(a). In this case, whether the soliton is effectively centered on a lattice maximum or minimum depends on its width. When the soliton width is small (medium), the soliton power is above (below) P_c and the slope is positive (negative), see Fig. 1(b). These properties are typical to soliton centered at lattice maximum (minimum) and show that they are unstable (stable). More importantly, ``mapping'' the stability as a function of the width allows us to accurately predict the dynamics of these soliton. For example, wide solitons for which the slope is positive, self-focus if the perturbation increases their power. However, once the soliton width reaches a width typical to solitons in a stable branch, the focusing is arrested and replaced by oscillations with respect to that stable soliton. Moreover, we show that if the perturbation increases the soliton power so that it exceeds P_c, the soliton undergoes collapse regardless of its stability conditions.

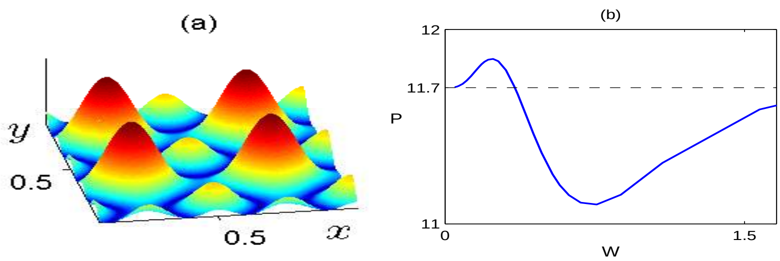

Fig. 1 (a) Side view of V. (b) Soliton power as a function of W(b).

WIDEBAND PROTECTION FILTER FROM HIGH POWER LASERS

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Optical systems are susceptible to saturation or damage caused by high power lasers. This problem calls for a device that will switch off the propagating power when the maximal allowed power is exceeded.

Generally, laser radiation of a specific wavelength is blocked by (linear) fixed spectral filters. However, when protection is required for several wavelengths, or a whole spectral band, the fixed spectral filters are no longer practical. We present a non-linear, solid-state passive optical protection filter operating in the visible and near IR. At input powers below threshold, the filter has high transmission over the whole spectral band. However, when the input power exceeds the threshold power, transmission is decreased dramatically. The transmission drop at high powers is attributed to a breakdown effect, which occurs in the active layer of the filter. The wideband filter is fast enough to block nanosecond laser pulses, so that even the first pulse is blocked.

We demonstrate experimental results of the nonlinear operation of the filter under single- or multiple-pulses. We also demonstrate protection of CCD cameras from high power pulses. The wideband protection filter operates in the IR and visible spectral ranges and can be readily used for protection of detectors, cameras, or eye safety.

Nanoscale Domain Engineering in $LiTaO_3$ Crystals for UV Second Harmonic Generation

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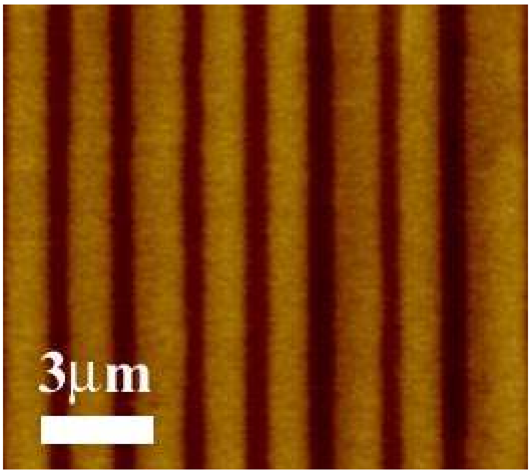
Periodically poled lithium tantalate ($LiTaO_3$) have attracted attention in recent years due to its promising application for ultraviolet (UV) second harmonic generation (SHG) by quasi phase matching (QPM). Calculations show that a UV laser (λ=300nm) based on SHG in $LiTaO_3$ crystal requires domain grating with a domain width of around 500nm. Scanning probe microscopy (SPM) seems to be feasible to tailor ferroelectric domains in submicron scale in bulk ferroelectric. We report on the application of high voltage atomic force microscope (HVAFM)[1] recently developed by our group for tailoring nanometer scale domain in the bulk of $LiTaO_3$ single crystals. Using the HVAFM we have fabricated periodic domain structures in 0.2mm thick stoichiometric $LiTaO_3$ samples with a period of less then 1 micron. In addition, the effect of the ambient humidity on the domain fabrication is discussed.



Piezoresponse force microscopy images of nanodomain grating fabricated in stoichiometric $LiTaO_3$ sample under low relative humidity.

[i] M. Molotskii, A. Agronin, P. Urenski, M. Shvebelman, G. Rosenman, and Y. Rosenwaks, Phys.Rev.Lett.90, 107601(2003).

All Optical Deflection Using Cascaded Nonlinear Interactions in Two-Dimensional Nonlinear Photonic Crystals

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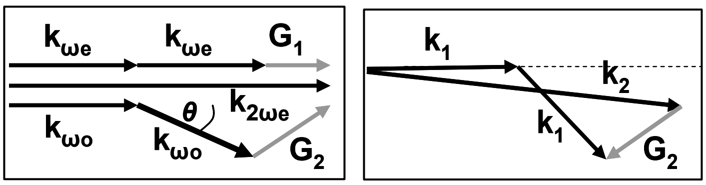
Cascaded nonlinear interactions by periodic two-dimensional (2D) modulation of the nonlinear coefficient enable the design of all-optical processes, as it provides simultaneous phase matching of two interactions. The fundamental beam can be controlled, by second harmonic generation (SHG) process, followed by a difference frequency generation (DFG) process, thereby generating a fundamental wave (FW) at a different direction or polarization. This enables the design of all-optical processes such as deflection and cross-polarization wave generation. Cascaded nonlinear interactions open a new concept of all-optical processes design.An all-optical deflector will be presented. The deflector is a 2D periodically poled Stoichiometric Lithium Tantalite Ferroelectric crystal (PPSLT). The deflector is controlled by the polarization of the input beam. The first process is a collinear SHG of input extra-ordinary polarization FW, using the d_{33} nonlinear coefficient, generating an extra-ordinary polarization SHW. The second process is a non-collinear DFG between the generated extra-ordinary polarization SHW and an input ordinary polarization FW, using the d_{31} nonlinear coefficient, generating a beam of the fundamental frequency.
In order to characterize the 2D PPSLT and to give good estimate on the refractive index of ordinary polarization in $LiTaO_3$ at room temperature, a SHG and sum frequency generation (SFG) experiments were performed on the PPSLT, to characterize each interaction independently.

S. M. Saltiel, Y. S. Kivshar, Opt. Lett. 27, 921 (2002).



(a) (b)

Figure 1: QPM vector schemes of (a) an all-optical deflector based on two cascaded interactions of SHG and DFG and of (b) the SFG experiment to characterize the 2D PPSLT.

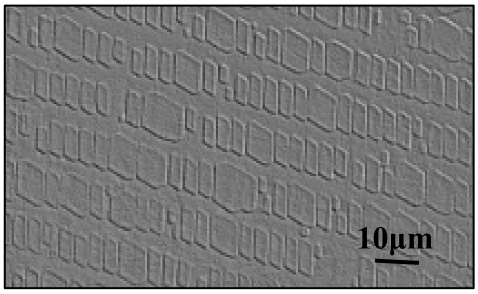


Figure 2: Microscope picture of the +Z side of the etched structure. The parallelograms are the inverted domains with sides of 3.6μm over 12μm.

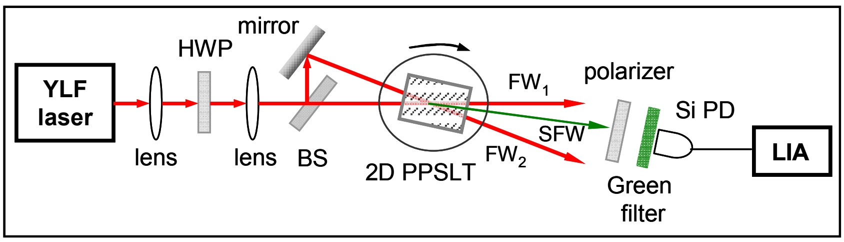


Figure 3: Experimental setup for characterizing the 2D PPSLT.

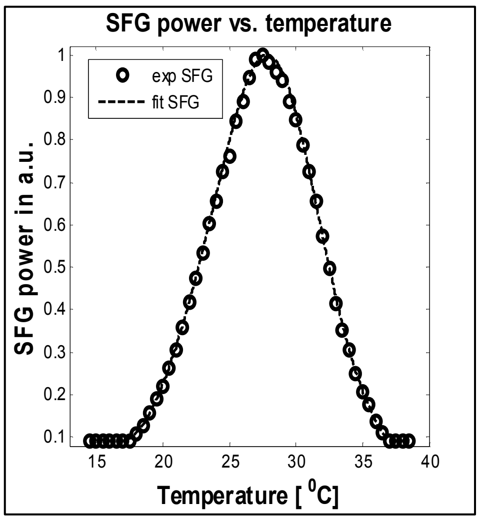


Figure 4: SFG power vs. Temperature.

COLLAPSE DYNAMICS OF SUPER-GAUSSIAN BEAMS

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It is well known that intense laser beams propagating in bulk Kerr medium can self-focus and collapse. Until recently, all theoretical and experimental results have shown that the beam collapses with a self-similar "Gaussian-like" profile, known as the Townes profile, which become smaller in width and taller in amplitude (intensity) as the beam collapses.

Recently, however, we have showed analytically and observed experimentally in water that super-Gaussian (flat-top) input beams collapse differently than Gaussian input beams. Indeed, super-Gaussians initially collapse with a self-similar *ring* profile which becomes smaller in radius and taller in amplitude (beam intensity) as it collapses. Subsequently, the ring breaks up into filaments, thereby creating a ring of filaments, see Figure 1. These results offer a compelling explanation for ring-shaped filamentation previously observed in experiments with high-power femtosecond lasers propagating in air. In addition, they suggest a method for producing multiple filaments patterns on a ring.

We also show that ultrashort super-Gaussian input pulses in the anomalous regime initially collapse with the three-dimensional analog of a ring, i.e., a spherical shell, and subsequently break up into a shell of spatio-temporal filaments.

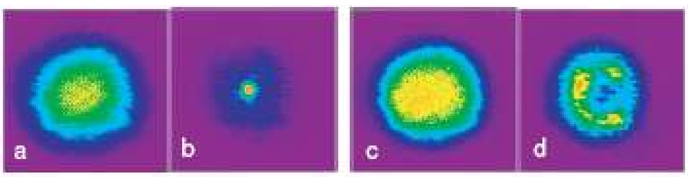

Figure 1. Images of the input and output intensity beam profiles for a 7-cm propagation distance (0.9 mm X 0.9 mm). (a) Gaussian input profile, (b) output beam with the Gaussian input and an input energy of $E = 5.6$ μJ, (c) super-Gaussian input profile, (d) output beam with a super-Gaussian input and an input energy of $E = 5.0$ μJ.

NUMERICAL SOLUTION OF HIGHLY NONLINEAR HELMHOLTZ EQUATIONS

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The one-dimensional nonlinear Helmholtz equation (NLH) models intense laser-beams in a Kerr-medium, such as in the *Fabry-Perot etalon*, or in *nonlinear optical gratings*. An advantage of the NLH over the more common nonlinear Schrodinger (NLS) model is that it correctly models both the forward- and backward-propagating components of the field. This feature is essential when modeling nonlinear optical resonators, counter-propagating beams, or backward-scattering. For example, it is known that for beam powers which exceed a certain threshold the Fabry-Perot etalon becomes a bistable device. This property can be modelled using the NLH, unlike the NLS. The NLH is, however, much harder to solve than the NLS. The NLH was solved numerically by the authors and by Suryanto et al., by freezing the Kerr nonlinearity and solving the resulting linear equation at each iteration. Such iteration-based methods, however, fail to converge even for moderate beam powers, well below the threshold for bistability. To solve the NLH at higher powers, we develop a variant of Newton's method, in which the NLH is separated into coupled real and imaginary equations, to which Newton's method can be applied. The resulting method succeeds in solving the NLH for high powers, well above the threshold for bistability, thus outperforming the previous iteration-based methods. Moreover, we developed a finite-volume approximation scheme for the NLH which handles material discontinuities, such as in grated materials. As a result, it is fourth-order accurate even for large material discontinuities, allowing for high accuracies at low grid resolutions.

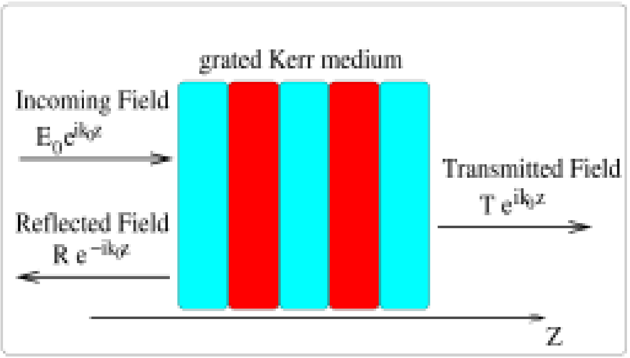

Figure 1: A grated Fabry-Perot device

In summary, we develop a Newton-based algorithm for the numerical solution of the NLH that can handle high beam powers and large material discontinuities.