Nonlinear Dispersion Properties Of Sub-wavelength Photonic Crystals

S. Vijayalakshmi, Y. Zhang, H. Grebel
Nonlinear Nanostructures laboratory
Electrical and Computer Engineering, New Jersey Institute of Technology
Newark, NJ-07102
Phone: (973) 596-3538, Fax: (973) 596-6513
grebel@njit.edu

Gul Yaglioglu, R. Dorsinville
Electrical Engineering Department,
City College and Graduate Center of The City University of New York
New York, NY-10031

C. W. White
Oak Ridge National Laboratory
Oak Ridge, TN-37831

Abstract:
Nonlinear pulse compression and pulse broadening have been demonstrated with a coherent array of sub-micron silica spheres embedded with silicon nanoparticles ('nano with nano').
OCIS codes: (320.7110) Ultrafast Nonlinear Optics

Nonlinear Dispersion Properties Of Sub-wavelength Photonic Crystals

S. Vijayalakshmi, Y. Zhang, H. Grebel
Nonlinear Nanostructures laboratory
Electrical and Computer Engineering, New Jersey Institute of Technology
Newark, NJ-07102
Phone: (973) 596-3538, Fax: (973) 596-6513
grebel@njit.edu

Gul Yaglioglu, R. Dorsinville
Electrical Engineering Department,
City College and Graduate Center of The City University of New York
New York, NY-10031

C. W. White
Oak Ridge National Laboratory
Oak Ridge, TN-37831

The most common pulse compression scheme is a combination of a frequency chirp with a dispersion compensator. The frequency chirp is achieved by nonlinear medium, most notably a Kerr medium. Periodic structures, such as, phase grating, have been used as a dispersion media needed for the compensation process [1]. Photonic crystals embedded with nonlinear material such as, silicon nanoclusters, bear the potential of incorporating the two requirements in one structure. The fcc structure of silica based opaline sample was ion implanted with Si ions. Following annealing, 5-6-nm clusters of silicon were formed within a 0.3-μm thick region, as determined by SEM and Raman spectroscopy [2]. The structures have been shown to be highly nonlinear [3], reaching index changes on the order of $|\delta n_{NL}|>0.1$ at λ=0.8-μm, and strongly dispersive [4]. Unlike Bragg fibers [5], we employ here a transverse scheme, namely, the dispersion is achieved via *transverse Bragg reflections* [6] while maintaining non-resonance conditions along the propagation direction.

For a 100-fs pulse, the delay-time introduced by the modal dispersion is $\delta\tau=\tau(\omega,q+1)-\tau(\omega,q)=(2q+1)0.2$-fs/μm. Shown in Fig. 1 is the broadening of the pulse by a non-implanted and implanted opaline samples as a function of angle. As predicted, a large broadening occurs at the transverse Bragg angle. Based on the previous arguments, the pulse propagation is made via multi-spatial modes.

The opal structure may compensate for frequency chirp introduced by an external means. Such pulse 'compression' for a 10-μm thick non-implanted opaline samples are shown in Fig. 2. The incoming pulse of 100-fs from a Ti:sapphire laser was positively chirped, without a change in the spectral width, using a 15-cm long, water-filled cuvette. The pulse duration after the water cuvette was 265-fs and the corresponding re-compression was 60-fs. The compression for the implanted sample was not as effective as the non-implanted sample. The reason is that the implanted region distorts the incident phase for the non-implanted segment thereby, resulting in a non-optimized effect. At low power levels (see also Fig. 1) the broadening from the combined effects is actually maximized. Also, owing to the negative signs of both linear and nonlinear dispersions one may expect a substantial broadening.

The nonlinear effect was indirectly demonstrated by measuring the pulse broadening of a 100-fs input pulse as a function of intensity. In Fig. 3 we show changes in pulse broadening as a function of pulse energy at two angles: (a) at the angle of maximum pulse compression and (b) at an angle of minimum compression. One may observe a saturation of index change for large energy densities. We also added the flat response of a non-implanted, 10-μm thick opaline structure. The latter demonstrates that, in general, the silica-based opaline structure does not contribute to the self-phase modulations.

In summary, we have shown that by incorporating nano silicon clusters (a nonlinear medium) within an opaline structure and employing a transverse diffraction scheme we were able to manipulate ultra-short pulses.

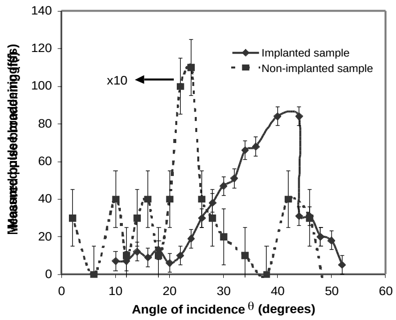

Fig. 1. Pulse broadening as a function of incident angle, θ. The theoretical estimation of the Bragg peaks are 19^0 and 43^0 for non-implanted and Si implanted samples, respectively.

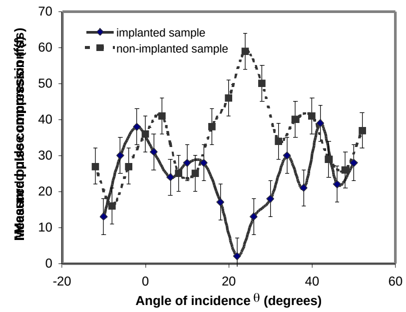

Fig. 2. Pulse compression for a pre-chirped pulse at 265-fs as a function of the incident angle, θ, for implanted and non-implanted 10-μm thick opaline samples. The implanted region was 0.3-μm.

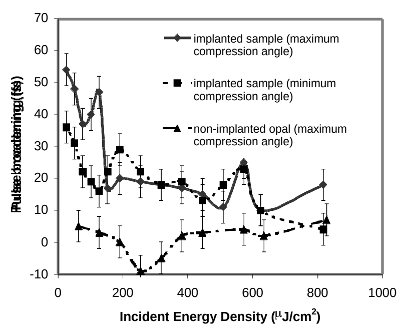

Fig. 3. Change in pulse broadening as a function of pulse energy density

Acknowledgement: Research sponsored by the Oak Ridge National Laboratory, managed by UT-Battelle, LLC, for the U.S. Department of Energy under contract DE-AC05-00OR22725.

References

1. E. B. Treacy, "Optical pulse compression with diffraction gratings", *IEEE J. QE.*, **QE 5**, 454 (1969)
2. Y. Zhang et al, "Linear properties of Si nanoclusters embedded in an ordered array of silica spheres", submitted to *Appl. Phys. Letts*, November, 1999.
3. M. Ajgaonkar, Y. Zhang H, Grebel and C. W. White, "Nonlinear optical properties of a coherent array of sub-micron SiO_2 spheres (opal) embedded with Si nanoparticle", *Appl. Phys. Letts*, **75**, 1532 (1999).
4. J. M. Tobias and H. Grebel, "Self-imaging in photonic crystals at sub-wavelength range", *Opt. Letts.*, 24, 1660 (1999).
5. B. Eggleton and R. Slusher, "Bragg grating solitons", *Phys. Rev. Letts*, **76**, 1627 (1996).
6. H. Grebel and W. Zhong, "Holographic interconnects: Transverse Bragg waveguides", *Opt. Letts*., **18**, 1123 (1993).
7. A. Yariv, "*Optical Electronics in Modern Communication*", Oxford University Press, New York, 5^{th} ed., p 225.