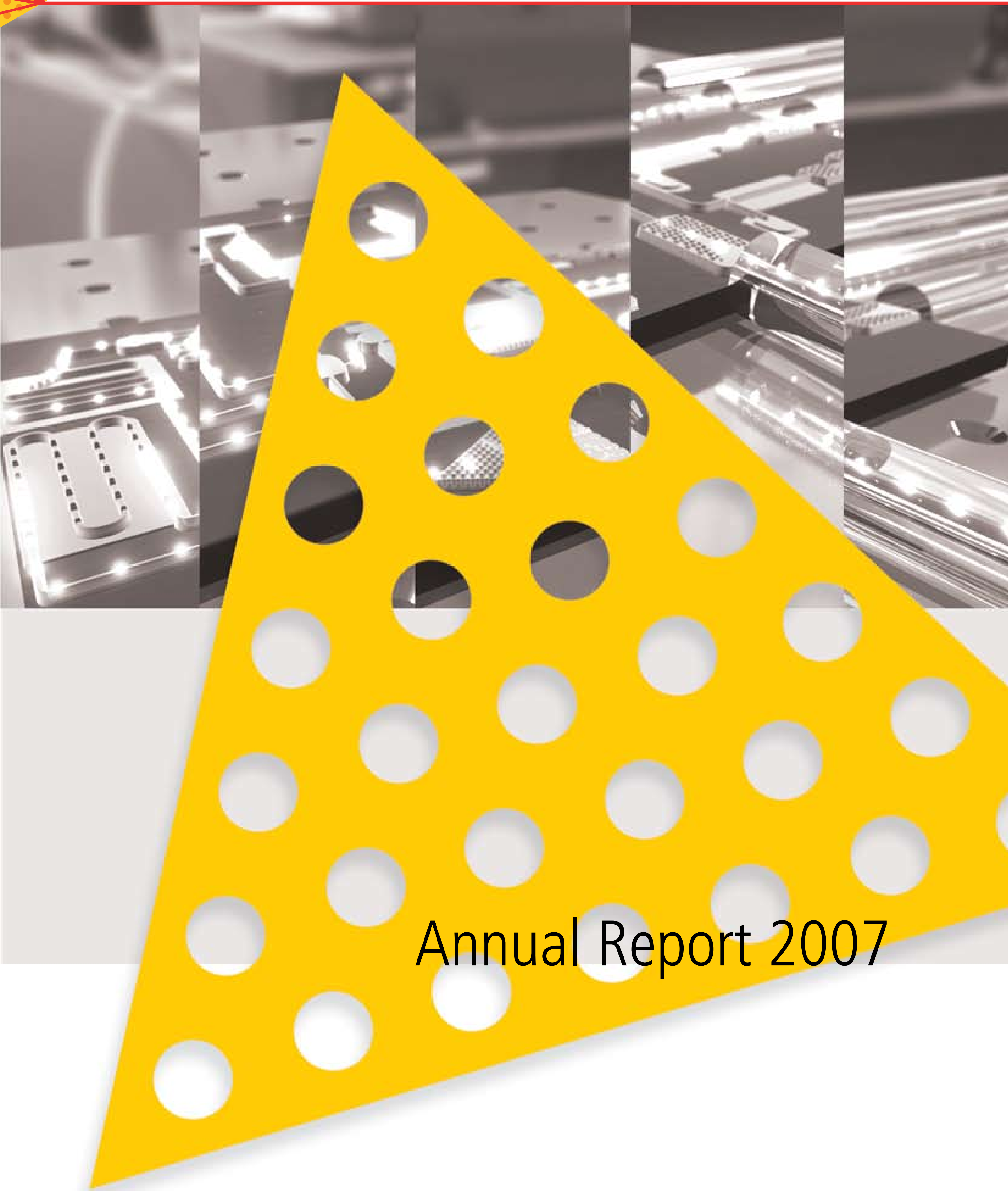
CUDOS The Centre for Ultrahigh bandwidth Devices for Optical Systems (CUDOS)

An Australian Research Council Centre of Excellence



Annual Report 2007

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[2] Jiafang Li, Baohua Jia, Guangyong Zhou and Min Gu, "Tuning spontaneous emission from near-infrared QDs through the angle-dependent band edge of a 3D photonic crystal," Applied Physics Letters 91, 254101 (2007).

[3] Michael J. Ventura, Craig Bullen, and Min Gu, "Direct laser writing of three-dimensional photonic crystal lattices within a PbS quantum-dot-doped polymer material," Opt. Express 15 (4), 1817-1822 (2007).

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[8] Elisa Nicoletti, Guangyong Zhou, Baohua Jia, Douglas Bulla, Barry Luther-Davies, and Min Gu, "Direct laser fabrication of three-dimensional microstructures in chalcogenide glasses," 2008 International Conference On Nanoscience and Nanotechnology, 25-29 February 2008 - Melbourne, Victoria, Australia.

TUNABLE MICROPHOTONICS

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Students: Bill Corcoran

Four year vision/long term goal and motivation

We aim to demonstrate control of light propagation in nanoscale two- and three-dimensional periodic photonic structures using innovative approaches for electrical and thermal tunability and optical actuation. This is crucial for the operation of all-optical photonic devices in future telecommunication, defence and sensing systems. Highly resolved wavelength selectivity and precisely defined dispersion features will be demonstrated with active tuning and stabilization.

We will achieve highly variable refractive indices in planar, fibre and 3D photonic crystal resonant structures by infiltrating them with liquid crystal and other nonlinear optical liquids and polymers. These can be controlled by applied voltage or internally by self-action. Tunable refraction, self-collimation, nonlinear propagation and switching will be explored. In a second approach we will use the electro-optic and nonlinear properties of $LiNbO_3$ to produce highly resonant and rapidly reconfigurable optical structures.

CUDOS strategy/competitive advantage

The Centre has strong programs of fundamental research in photonic crystal structures and nonlinear approaches to achieve tunability, combined with experimental capabilities in lithium niobate platforms, Bragg grating production and techniques for infiltration of photonic crystals with nonlinear materials including liquid crystal.

We also benefit from strong alliances with end users with well-articulated requirements for specific applications.

Collaborative links

The Centre collaborates with DSTO on this project.

Goals for 2007

This Flagship commenced in 2007 with a goal for the year to build expertise in a number of areas: Bragg gratings in lithium niobate, fluid infiltrated structures and periodically poled lithium niobate, each of which offers a path towards optical actuation and tunability.

1. Bragg Gratings on $LiNbO_3$

The aims for 2007 were to realise Bragg gratings on $LiNbO_3$, primarily using photorefraction due to iron (Fe) dopants. This project is a collaboration between RMIT and The University of Sydney with input from ANU.

The project steps were:

a. Demonstrate Photofractive Fabry-Perot on $LiNbO_3$

b. Demonstrate Bragg grating on $LiNbO_3$

c. Demonstrate Sampled Bragg grating on $LiNbO_3$

d. Demonstrate Tunable, sampled $LiNbO_3$

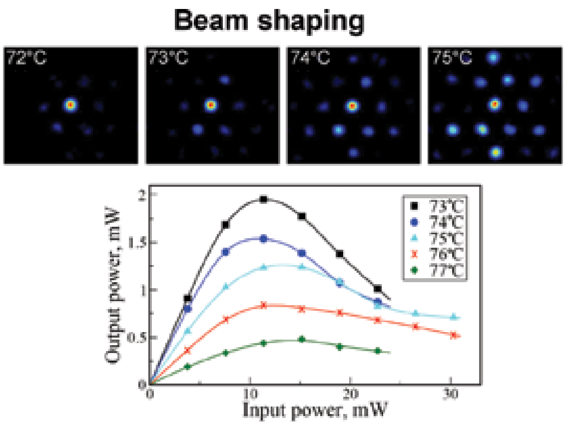

Fig 1: Photonic crystal fiber with solid core, surrounding holed fluid infiltrated Images: linear output intensity distribution at various temperatures; graph: non-linear behavior with output power in the central waveguide varying as a function of input power at each different temperature [1].

[1] C. R. Rosberg, F. H. Bennet, D. N. Neshev, P. D. Rasmussen, O. Bang, W. Krolikowski, A. Bjarklev, and Y. S. Kivshar, "Tunable diffraction and self-defocusing in liquid-filled photonic crystal fibers," Opt. Express 15, 12145-12150 (2007)

The project was delayed initially due to the need to build a dedicated holographic grating writing system as the Chalcogenide system was fully utilised for a parallel project. This meant that the facilities were not available until approximately mid-year. Once dedicated facilities were available, a Fabry-Perot configuration was attempted with waveguides provided by RMIT. Tuning of the refractive index of the waveguide was observed, but it was discovered that this effect was dominated by thermal effects and did not constitute photorefraction. To obtain an unambiguous measurement, we modified the equipment to attempt to write bulk gratings in $LiNbO_3$ using two beam holography. This was successful with unprocessed Fe doped samples, producing moderately strong gratings over a period of hours. Similar photorefraction was not observed with $LiNbO_3$ waveguides. It was realised that the Fe impurities were oxidised during the diffusion process. A post-process to reduce the Fe impurities is required (consisting of annealing in Argon).

Experiments are currently underway to successfully reduce the Fe doped waveguide. Once this has been achieved, we will repeat the bulk grating experiments to verify that the samples are again photorefractive. We can then attempt to realise Bragg gratings in the waveguides on the samples. This will enable us to design sampled and tuneable gratings and also design microwave photonic components based on these.

Progress on this project has been limited due to resources, inevitable with any new research activity. Initial delays were caused by equipment constraints and student shortages, both of which will be addressed in 2008.

2. Fluid Infiltrated Structures

This project aimed to establish tunable fluid infiltrated structures as a nonlinear platform for CUDOS. It is primarily a collaboration between ANU and RMIT University with input from The University of Sydney.

The aims for 2007 for this sub-project were:

a. Demonstrate linear/nonlinear properties of fluid infiltrated photonic crystal fibre

b. Demonstrate thermally tuned linear/nonlinear properties of fluid infiltrated PCF

c. Develop fluid infiltrated planar waveguide platform

d. Identify and become competent with fast nonlinear & electrically tunable fluids

This project has been most successful, with the ambitious goals for the year met and with a large number of publications resulting.

We have suggested theoretically and demonstrated experimentally a novel platform for the study of tunable nonlinear light propagation in two-dimensional discrete systems, based on photonic crystal fibres filled with high index nonlinear liquids. Using the infiltrated cladding region of a photonic crystal fibre as a nonlinear waveguide array, we have experimentally demonstrated highly tunable beam diffraction and thermal self-defocusing, and realize a compact all-optical power limiter based on a tunable nonlinear response. (Fig.1) This represents successful completion of objectives a) and b) above.

A planar waveguide system in the elastomer PDMS has been developed at RMIT. It has been shown that air filled channels can be maintained without collapse over cm length scales with micron dimensions. Issues remain with end-facet preparation and fluid infiltration of this hydrophobic platform. This platform will be pursued further in 2008 with the dedicated attention of Research Assistant Eike Zeller. (See Fig.2) This represents partial success for objective c) above, where progress has been limited by availability of research personnel at RMIT.

We have analyzed the optical Fréedericks transition in a slab of a nematic liquid crystal placed in a one-dimensional periodic photonic crystal. For various polarizations of the excitation light (circular and elliptical), we have studied theoretically the effect of infiltration and the induced defect on the light-induced transmission of the structure. We have predicted that the periodic structure allows reducing the threshold intensity up to several orders of magnitude. In addition, our results show that the periodicity of the underlying dielectric structure can stabilize the director dynamics, thus offering a novel and attractive opportunity to design new all-optically tunable photonic bandgap structures based on infiltrated liquid crystal materials. This represents success in the pursuit of objective d) above.

This project has attracted several new students in 2007 including Francis H. Bennet (Physics Dept. ANU) who has completed his Honours Thesis "Nonlinearity in temperature tuned liquid infltrated photonic crystal fibres". Francis Bennet is continuing as a PhD student with the Nonlinear Physics Group at ANU also in fluid infiltration. Urszula Laudyn, overseas PhD student from the Warsaw University of Technology, July 2007- January 2008 was studying liquid infiltrated fibres. At RMIT the Students Mahyar Nasabi (Honors), Francisco Tovar (PhD, Microfluidics) and Tanveer Mahmud (PhD, Optofluidics) are working on the planar fluidic platform.

3. Periodically Poled $LiNbO_3$

This sub-project aimed to establish a platform for fast nonlinearity on $LiNbO_3$ that was compatible with existing Ti waveguide and electro-optic tuning technology. The objectives of this project for 2007 were:

a. Set up waveguide poling facility

b. Demonstrate poling of Bulk Z-cut

c. Demonstrate periodic poling of Z-cut waveguide

d. Attempt poling of X-cut waveguide

A high-voltage amplifier was purchased and this was configured with a wave form generator to achieve the poling pulse profile. A poling cell suitable for full wafers has been realised. This cell provides an interface between liquid electrodes and the wafer on both sides. Z-cut wafers patterned with 5-15µm features have

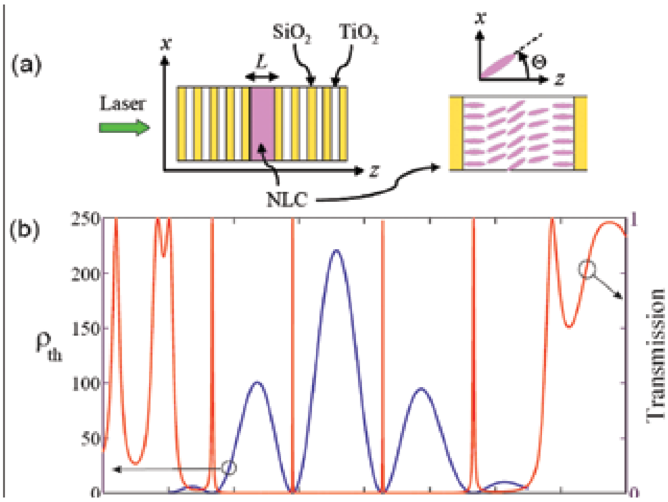

Fig 2: Spectral modulation of the Freedericksz transition: a) a periodic structure, consisting of alternating layers of SiO_2 and TiO_2, contains a liquid crystal defect. Molecules of liquid crystal orient along the rubbing direction; b) it is possible to observe first (blue) or second (red) order types of transition for the same liquid crystal, depending on the pumping wavelength.

been loaded into the cell and poled. Monitoring of the poling current has indicated that poling was achieved. The poled wafers were then etched in heated hydrofluoric acid to reveal the poled and unpoled domains. The masked patterns were clearly visible on both faces of the wafer indicating that the pattern had been successfully poled through the sample. Features of 5 μm were evident on both sides indicating that the resolution achieved was very promising. These results indicate successful completion of objectives a) and b) above.

The continued progress on this project was limited by human resources available. Coordination with the poling facilities soon to be available at the Bandwidth Foundry will also be pursued.

Published papers

(1) Infiltrated systems, nonlocal response

1. Christian R. Rosberg, Francis H. Bennet, Dragomir N. Neshev, Per D. Rasmussen, Ole Bang, Wieslaw Krolikowski, Anders Bjarklev, and Yuri S. Kivshar Tunable diffraction and self-defocusing in liquid-filled photonic crystal fibers Opt. Express 15, 12145 (2007)
2. Alexander Minovich, Dragomir N. Neshev, Alexander Dreischuh, Wieslaw Krolikowski, and Yuri S. Kivshar Experimental reconstruction of nonlocal response of thermal nonlinear optical media Opt. Lett. 32, 1599 (2007)

(2) Photonic lattices

3. Anton S. Desyatnikov, Yuri S. Kivshar, Valery S. Shchesnovich, Solange B. Cavalcanti,and Jandir M. Hickmann Resonant Zener tunneling in two-dimensional periodic photonic lattices Opt. Lett. 32, 325 (2007)
4. Ivan L. Garanovich, Alexander Szameit, Andrey A. Sukhorukov, Thomas Pertsch, Wieslaw Krolikowski, Stefan Nolte, Dragomir Neshev, Andreas Tuennermann, and Yuri S. Kivshar Diffraction control in periodically curved two-dimensional waveguide arrays Opt. Express 15, 9737 (2007)
5. Ivan L. Garanovich, Andrey A. Sukhorukov, and Yuri S. Kivshar Nonlinear diffusion and beam self-trapping in diffraction-managed waveguide arrays Opt. Express 15, 9547 (2007)
6. Rodrigo A. Vicencio, Sergej Flach, Mario I. Molina and Yuri S. KivsharDiscrete surface solitons in two-dimensional anisotropic photonic lattices Physics Letters A, Volume 364, Issues 3-4, 30 April 2007, Pages 274-276
7. I. Babushkin, A. Husakou, J. Herrmann, and Yuri S. Kivshar Frequency-selective self-trapping and supercontinuum generation in arrays of coupled nonlinear waveguides Opt. Express 15, 11978 (2007)
8. Dumitru Mihalache, Dumitru Mazilu, Falk Lederer, and Yuri S. Kivshar Interface discrete light bullets in waveguide arrays Opt. Lett. 32, 2091 (2007)
9. Mario I. Molina and Yuri S. Kivshar Interface localized modes and hybrid lattice solitons in waveguide array Physics Letters A, Volume 362, Issue 4, 5 March 2007, Pages 280-282
10. Yuri S. Kivshar and Mario I. Molina Nonlinear surface modes and Tamm states in periodic photonic structures Wave Motion, Volume 45, Issues 1-2, November 2007, Pages 59-67
11. Dumitru Mihalache, Dumitru Mazilu, Falk Lederer, and Yuri S. Kivshar Spatiotemporal surface solitons in two-dimensional photonic lattices Opt. Lett. 32, 3173 (2007)
12. Sebastian Koke, Denis Träger, Philip Jander, Michael Chen, Dragomir N. Neshev, Wieslaw Krolikowski, Yuri S. Kivshar, and Cornelia Denz Stabilization of counterpropagating solitons by photonic lattices Opt. Express 15, 6279 (2007)
13. Andrey A. Sukhorukov, Dragomir N. Neshev, and Yuri S. Kivshar Shaping and control of polychromatic light in nonlinear photonic lattices Opt. Express 15, 13058 (2007)

(3) Phase-matching and harmonic generation

14. Robert Fischer, Dragomir N. Neshev, Solomon M. Saltiel, Andrey A. Sukhorukov,Wieslaw Krolikowski, and Yuri S. Kivshar Monitoring ultrashort pulses by transverse frequency doubling of counterpropagating pulses in random media Appl. Phys. Lett. 91, 031104 (2007)
15. Jose Trull, Crina Cojocaru, Robert Fischer, Solomon M Saltiel, Kestutis Staliunas, Ramon Herrero, Ramon Vilaseca, Dragomir N Neshev, Wieslaw Krolikowski and Yuri S Kivshar Second-harmonic parametric scattering in ferroelectric crystals with disordered nonlinear domain structures Opt. Express 15, 85868, 2007
16. Benjamin F. Johnston, Peter Dekker, Solomon M. Saltiel, Yuri S. Kivshar, and Michael J. Withford Energy exchange between two orthogonally polarized waves by cascading of two quasi-phase-matched quadratic processes Opt. Express 15, 13630 (2007)

(4) Optical switching, solitons, etc

17. Oleg A. Egorov, Falk Lederer, and Yuri S. Kivshar How does an inclined holding beam affect discrete modulational instability and solitons in nonlinear cavities? Opt. Express 15, 4149 (2007)
18. Yuri Kivshar Optical switching: Capillary action Nat. Photonics 1, 143 (2007)
19. Andrey E. Miroshnichenko, Mario I. Molina, and Yuri S. Kivshar Localized modes and bistable scattering in nonlinear network junctions Phys. Rev. E 75, 046602 (2007)
20. Sergei F. Mingaleev, Andrey E. Miroshnichenko, and Yuri S. Kivshar Low-threshold bistability of slow light in photonic-crystal waveguides Opt. Express 15, 12380 (2007)