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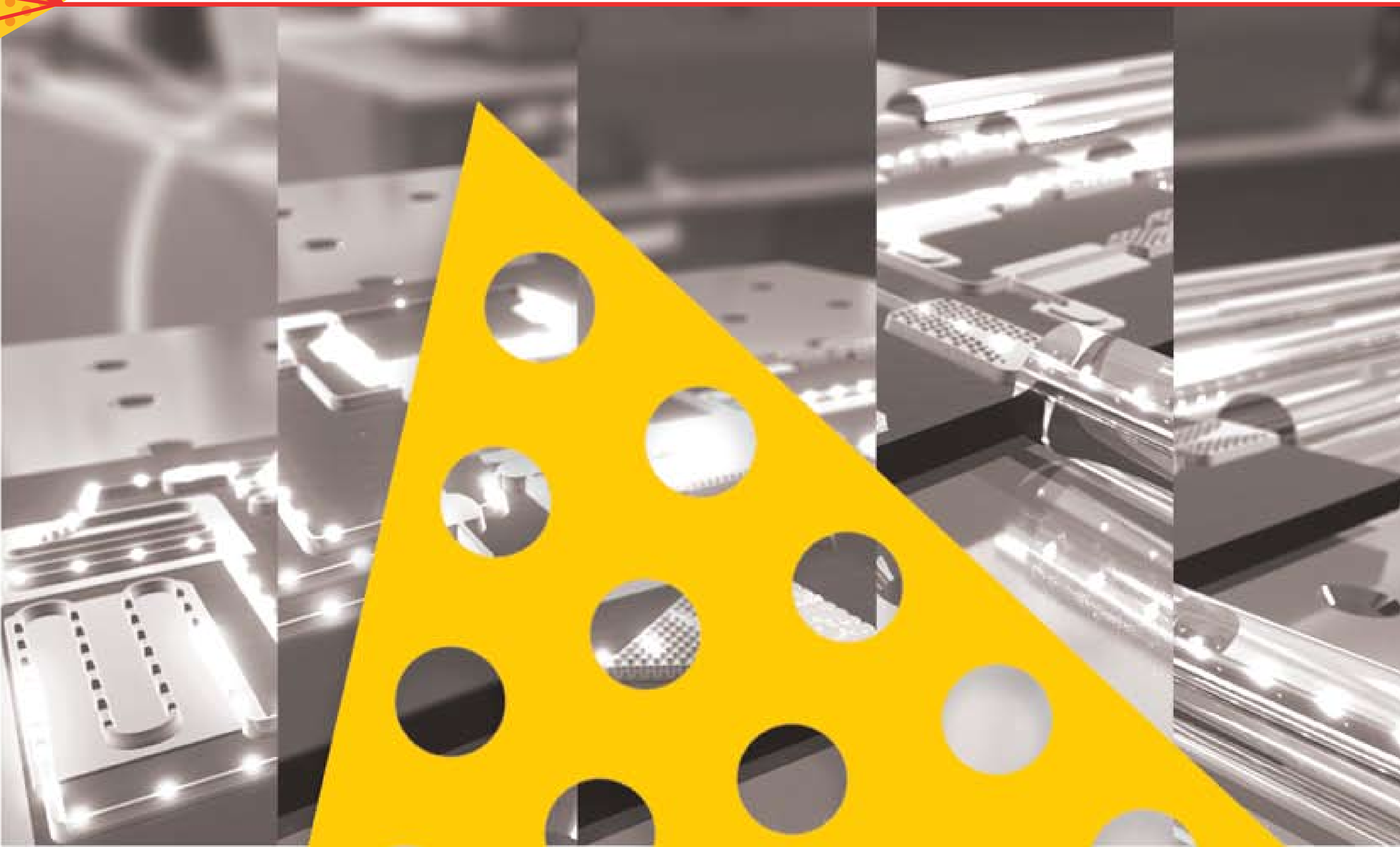
An Australian Research Council Centre of Excellence



Annual Report 2007

Professor Yuri Kivshar

Yuri Kivshar received his PhD in 1984 from the USSR Academy of Science and was at the Institute for Low Temperature Physics and Engineering (Kharkov, Ukraine). From 1988 to 1993 he worked at different research centers in USA, France, Spain, and Germany. In 1993 he accepted an appointment at the Research School of Physical Sciences and Engineering of the Australian National University where presently he is Professor and Head of the Nonlinear Physics Center. Yuri Kivshar published more than 350 research papers in peer-reviewed journals including more than 15 book chapters and review articles and 2 books published in 2003 (Academic Press, translated to Russian in 2005) and 2004 (Springer-Verlag, currently being translated to Russian). His interests include nonlinear guided waves, optical solitons, nonlinear atom optics, photonic crystals, and stability of nonlinear waves. Professor Yuri Kivshar was a recipient of the Medal and Award of the Ukrainian Academy of Science (1989), the International Pnevmatikos Prize in Nonlinear Physics (1995), the Pawsey Medal of the Australian Academy of Science (1998). In 1999 he was appointed as an (first Australian) Associate Editor of the Physical Review, and in 2002 he was elected to the Australian Academy of Science. He is Fellow of Optical Society of America and American Physical Society. His recent awards include the Boas Medal of the Australian Institute of Physics (2006) and the Lyle Medal of the Australian Academy of Sciences (2007).

Awards in 2007

Lyle Medal of the Australian Academy of Sciences (the highest award of the AAS in physics); The Peter Baum Award of the Australian National University (the most distinguished award of ANU)

Key areas of research contribution within the Centre

Nonlinear optics, nanophotonics, photonic crystals, parametric processes and frequency conversion, metamaterials, all-optical devices and technologies

Major international visits

In 2007 he visited more than 15 research laboratories including the University of Tokyo (Japan), University of Alagos (Brazil), Sapporo University (Japan), Matsuyama University (Japan); Max-Plank Research Group in Photonics (Erlangen, Germany), Technical University of Darmstadt (Germany), and many others.

International lecture courses

Yuri Kivshar was invited to deliver two international lectures courses: (1) "Nonlinear Photonic Cryustals, Solitons, and Metamaterials" at the X Jorge Andre Swiece School on Quantum Optics and Nonlinear Optics, Alagos (BRAZIL) March 2007; and (2) "Nonlinear optics in periodic media"; Universitat Politecnica de Catalunya (UPC) Terrassa, Barcelona, Spain May 2007.

Describe key areas of research activity

Yuri Kivshar leads several research projects within the CUDOS program. His main research activity aims to develop innovative concepts of all-optical communication and information technologies and to carry out both theoretical and experimental studies on the photonic-crystal physics and engineering, optical solitons, and microphotonic nonlinear switching devices in order to promote the new field of photonic crystals, to enhance its development in Australia and provide linkages between leading edge R&D and industry in an important emerging technology. In particular, his current research activities fit at least two CUDOS Flagship projects **Slow Light** and **Tunable Microphotonics**, involving the studies of spatiotemporal dynamics of light propagation, nonlinear interaction and control of light in periodic photonic structures, and theoretical studies of photonic crystals and related devices.

Research achievements during 2007

Slow-light switching in nonlinear Bragg-grating couplers

We study propagation and switching of slow-light pulses in nonlinear couplers with phase-shifted Bragg gratings. We demonstrate that power-controlled nonlinear self-action of light can be used to compensate for dispersion-induced broadening of pulses through the formation of gap solitons, to control pulse switching in the coupler, and to tune the propagation velocity [Sangwoo Ha et al., Opt. Lett. **32**, 1429 (2007)].

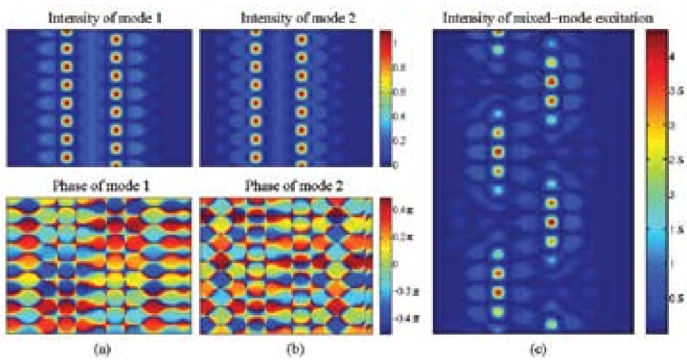


Fig 1: Slow-light waveguide coupler. (a,b) Intensity (top) and phase (bottom) of the transverse magnetic field distributions for the band-edge modes of antisymmetric coupler with (a) positive and (b) negative wavenumbers, respectively. (c) Intensity of the simultaneously excited modes.

Shaping and control of polychromatic light in nonlinear photonic lattices

Our recent results include spatio-spectral control, diffraction management, broadband switching, and self-trapping of polychromatic light in periodic photonic lattices in the form of rainbow gap solitons, polychromatic surface waves, and multigap color breathers. We show that interplay of wave scattering from a periodic structure and interaction of multiple colors in media with slow nonlinear response can be used to selectively separate or combine different spectral components. We use an array of optical waveguides fabricated in a $LiNbO_3$ crystal to actively control the output spectrum of the supercontinuum radiation and generate polychromatic gap solitons through a sharp transition from spatial separation of spectral components to the simultaneous spatiospectral localization of supercontinuum light. We also show that by introducing specially optimized periodic bending of waveguides in the longitudinal direction, one can manage the strength and type of diffraction in an ultra-broad spectral region and, in particular, realize the multicolor Talbot effect [A. Sukhorukov et al, Opt. Express **15**, 13058 (2007)].

Low-threshold bistability of slow light in photonic-crystal waveguides

We analyze the resonant transmission of light through a photonic-crystal waveguide side coupled to a Kerr nonlinear cavity, and demonstrate how to design the structure geometry for achieving bistability and all-optical switching at ultralow powers in the slow-light regime. We show that the resonance quality factor in such structures scales inversely proportional to the group velocity of light at the resonant frequency and thus grows indefinitely in the slow-light regime. Accordingly, the power threshold required for all-optical switching in such structures scales as a square of the group velocity, rapidly vanishing in the slow-light regime [S. Mingaleev et al, Opt. Express **15**, 12380 (2007)]

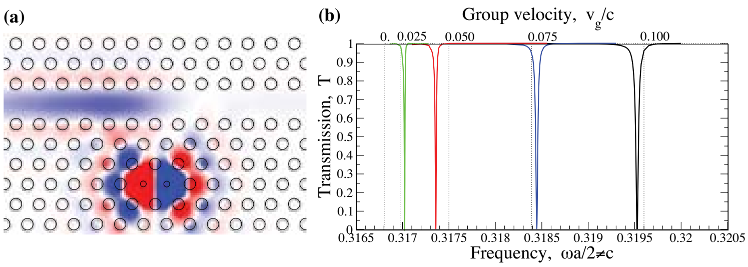


Fig 2: All-optical switching of slow light. Double-defect waveguide-cavity structure with the cavity created by two defect rods. (a) Electric field at the resonance reflection, (b) Transmission spectra for different values of the radius

Self trapping and supercontinuum generation in coupled nonlinear waveguides

We study spatiotemporal dynamics of soliton-induced two octave-broad supercontinuum generated by fs pulses in an array of coupled nonlinear waveguides. We show that after fission of the input pulse into several fundamental solitons, red and blue-shifted non-solitonic radiation, as well as solitons with lower intensity, spread away in transverse direction, while the most intense spikes self-trap into spatiotemporal discrete solitons [I Babushkin et al, Opt. Express 15, 11978 (2007)]

Energy exchange by cascading in quasi-phase-matched quadratic processes

We demonstrate energy exchange between two orthogonally polarized optical waves as a consequence of a two-color multistep parametric interaction. The energy exchange results from cascading of two quasi-phase-matched (QPM) second-harmonic parametric processes, and it is intrinsically instantaneous. The effect is observed when both the type-I (ooe) second-harmonic generation process and higher QPM order type-0 (eee) second-harmonic generation processes are phase-matched simultaneously in a congruent periodically-poled lithium niobate crystal. The two second-harmonic generation processes share a common second-harmonic wave which couple the two cross-polarized fundamental components and facilitate an energy flow between them. We demonstrate a good agreement between the experimental data and the results of numerical simulations [B. Johnston et al., Opt. Express **15**, 13630 (2007)].

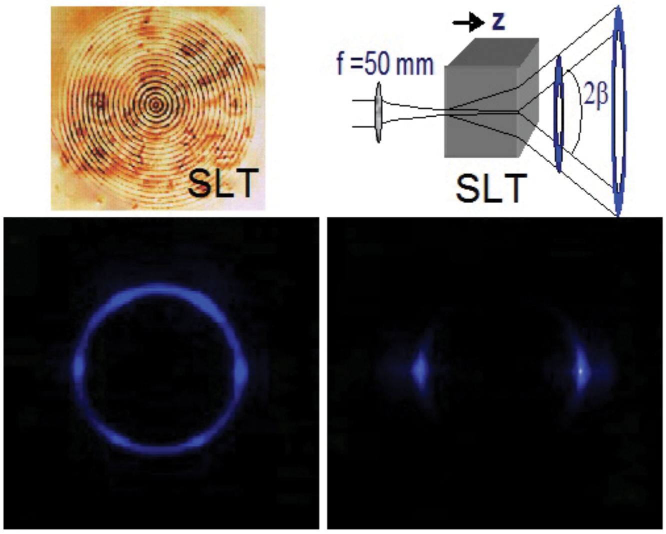


Fig 3: Second-harmonic generation by annularly poled structures. Above: Front facet of the annular periodically poled Stoichiometric Lithium Tantalate (SLT) sample and schematic of the experiment. Below: far-field image of the second-harmonic rings.

Stable discrete surface light bullets

We analyze spatiotemporal light localization near the edge of a semi-infinite array of weakly coupled nonlinear optical waveguides and demonstrate the existence of a novel class of continuous-discrete spatiotemporal solitons, the so-called discrete surface light bullets. We show that their properties are strongly affected by the presence of the surface. To this end the crossover between surface and quasi-bulk bullets is studied by analyzing the families of solitons propagating at different distances from the edge of the waveguide array [D. Michakache et al, Opt. Express **15**, 589 (2007)]

Suppression of Anderson Localization in Disordered Metamaterials

We study wave propagation in mixed, one-dimensional disordered stacks of alternating right- and left-handed layers and reveal that the introduction of metamaterials substantially suppresses Anderson localization. At long wavelengths, the localization length in mixed stacks is orders of magnitude larger than for normal structures, proportional to the sixth power of the wavelength, in contrast to the usual quadratic wavelength dependence of normal systems. Suppression of localization is also exemplified in long-wavelength resonances which largely disappear when left-handed materials are introduced [A. Asatryan et al., Phys Rev. Lett. **99**, 193902 (2007)]

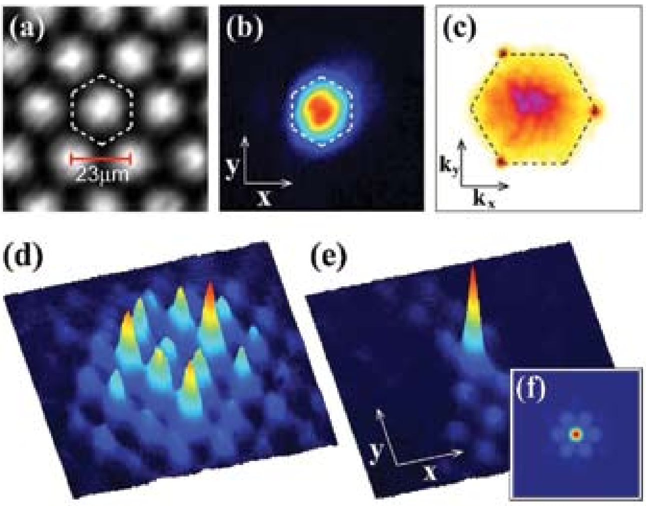


Fig 4: Observation of light localization in triangular lattices. Experimental images of (a) triangular lattice, (b) single-beam input intensity distribution, and (c) Fourier spectrum of input and lattice beams. (d), (e) Measured linear discrete diffraction and nonlinear self-trapping, respectively, from the top of the first band. (f) Numerically calculated intensity of discrete soliton.

In addition, together with Prof. Wieslaw Krolikowski, Yuri Kivshar leads the experimental studies of linear and nonlinear aspects of localization and control of light in periodic photonic structures, including the studies of nonlinear effects in fabricated photonic periodic structures.

Some of the major recent highlights of those projects are (see report by W Krolikowski for further details):

Nonlinear spectral-spatial control and localization of supercontinuum radiation [D. Neshev et al. Phys. Rev. Lett. **99**, 123901 (2007)]. The first observation of spatiospectral control and localization of supercontinuum light through the nonlinear interaction of spectral components in extended periodic structures.

Tunable diffraction and self-defocusing in liquid-filled photonic crystal fibers [C. Rosberg, et al. Opt. Express **15**, 12145 (2007)]. Demonstration of a novel platform for the study of tunable nonlinear light propagation in two-dimensional discrete systems, based on photonic crystal fibers filled with high index nonlinear liquids.

Monitoring ultrashort pulses by transverse frequency doubling of counterpropagating pulses in random media [R. Fischer, et al. Appl. Phys. Lett. **91**, 031104 (2007)]. Demonstration that strontium Barium niobate ferroelectric crystals with randomly distributed antiparallel ferroelectric domains of various sizes can be used to realize broad-band second harmonic generation via the quasi-phase matching technique.