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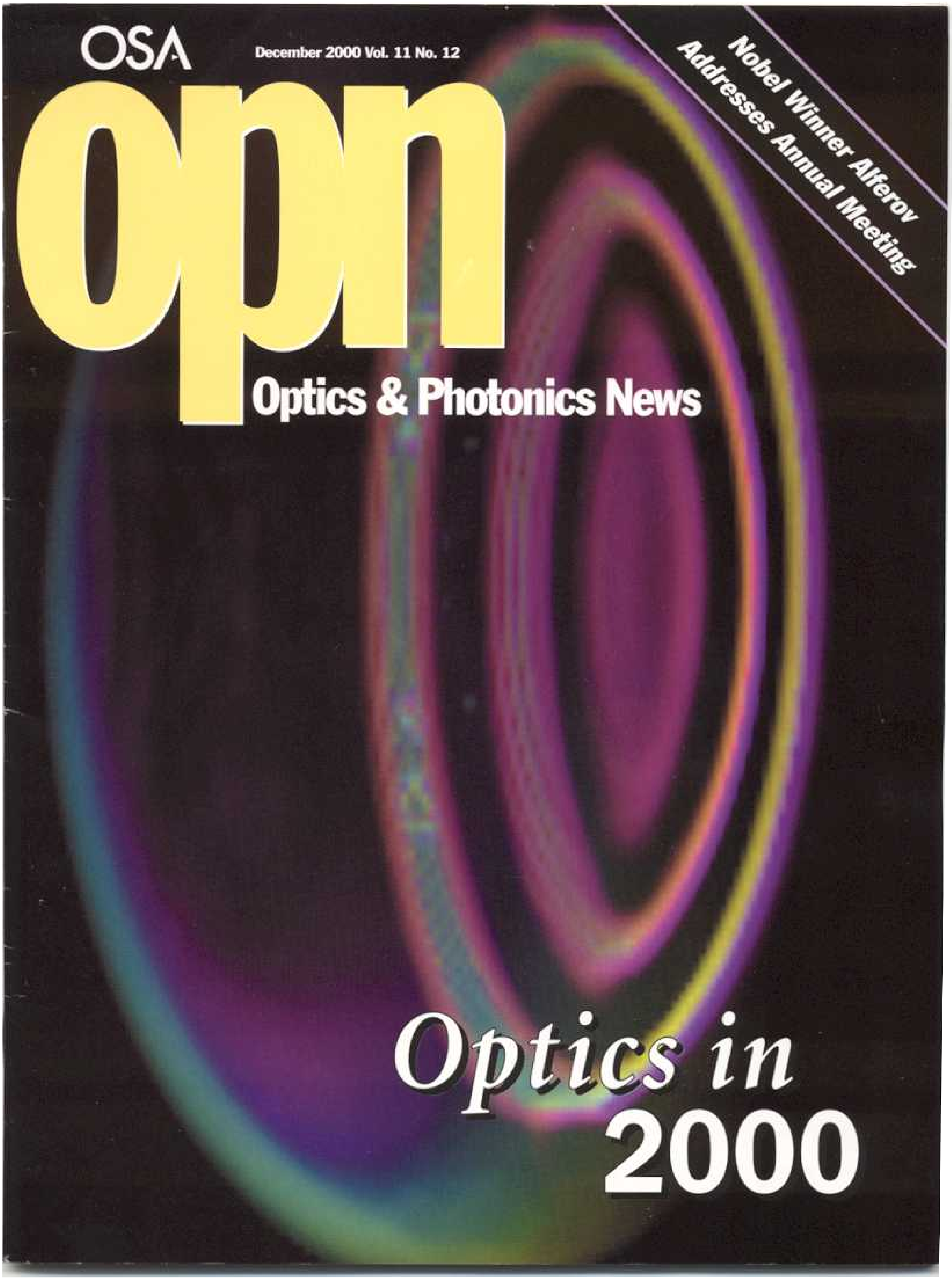
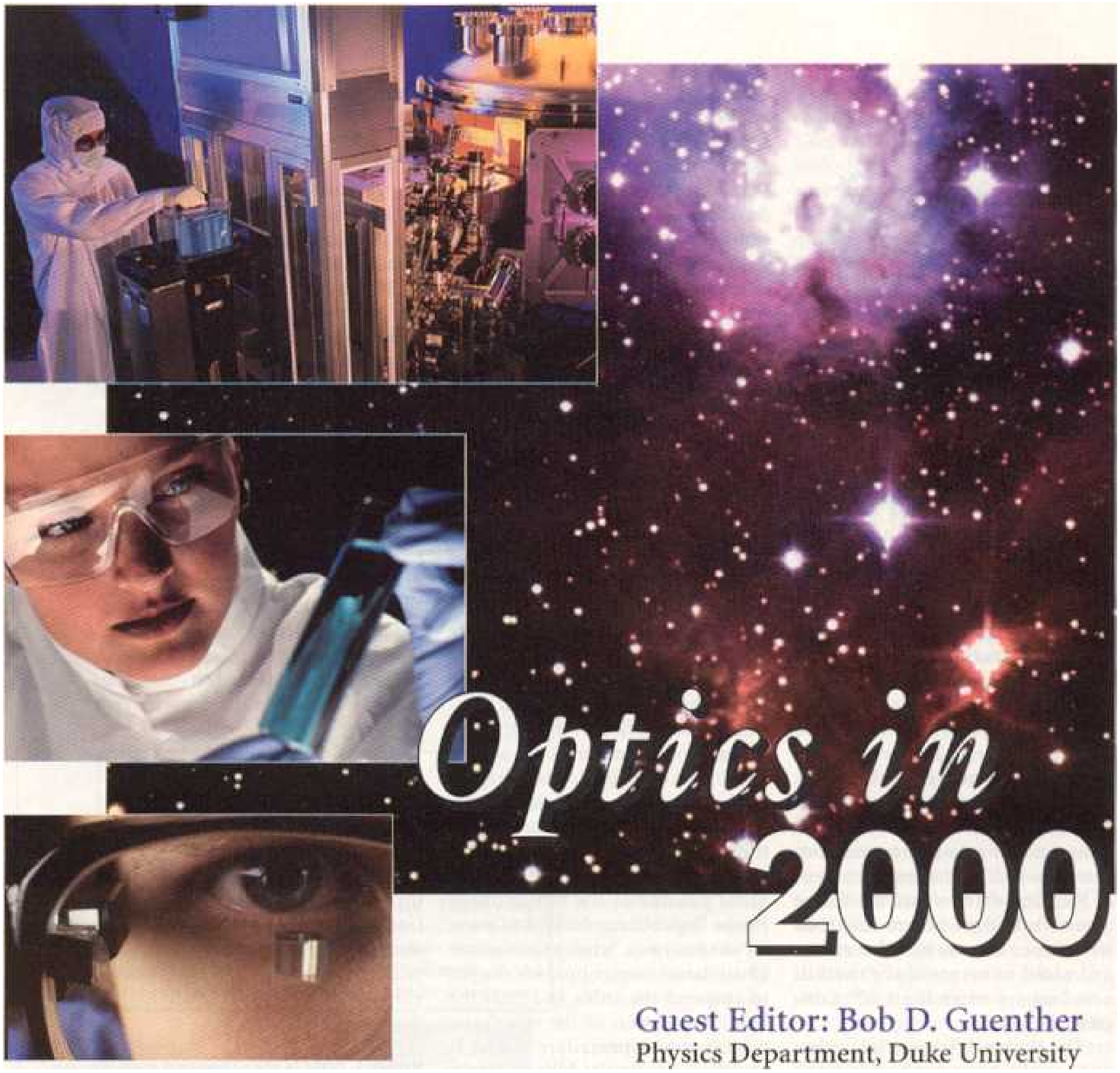
Optics & Photonics News

Nobel Winner Alferov Addresses Annual Meeting



Optics in 2000



Optics in 2000

Guest Editor: Bob D. Guenther
Physics Department, Duke University

Examples of the most significant recent research in optics and engineering are published each year in the December issue of OPN. This issue is comprised of short descriptions of the "hottest" topics in current optics research. Selection criteria applied to submissions are as follows:

- **the accomplishments described must have been published in a refereed journal in the year prior to publication in OPN;**
- **the work must be illustrated in a clear, concise manner, comprehensible to the at-large optics community;**
- **the topical area as a whole must be described, and the importance of the research must be detailed.**

There are no requirements in the selection process for inclusion of specific topical areas. When a large number of submissions are received for a specific area, this is taken as evidence that the topic has been fertile ground for activity and research over the course of the preceding year. OPN strives to ensure that engineering, science, and technology are all represented. The number of papers accepted overall is limited by space.

With 33 papers accepted, 2000 has proven to be another successful year. OPN and OSA would like to thank the hundreds of researchers from all over the world who submitted summaries to Optics in 2000.

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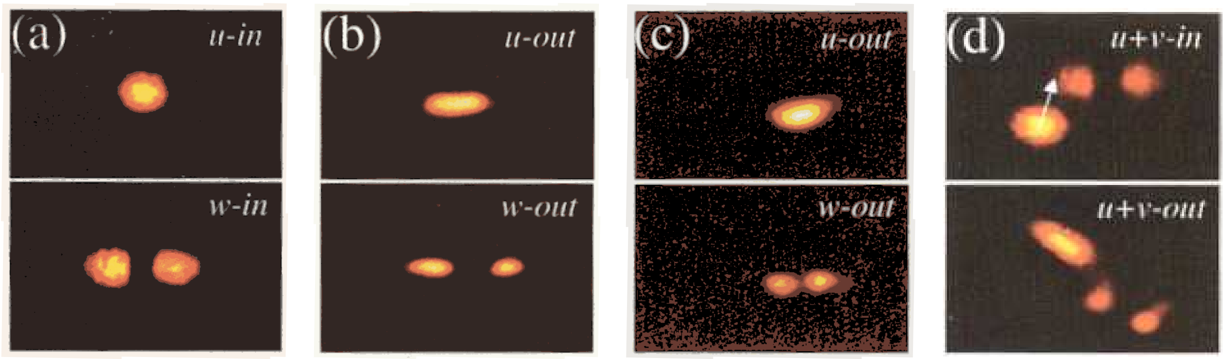


Dipole-Mode Vector Solitons Figure 1. Experimental demonstration of the formation of the dipole-mode soliton (a)-(c) as well as transformation of the linear-to-angular momentum in the collision event between a dipole-mode soliton and a scalar soliton, mutually coherent with the dipole component of the composite structure (d). The following are shown: (a) Input intensity of the fundamental (u) and dipole (w) components. (b) Output structure of dipole and fundamental beams after individual propagation in the nonlinear crystal. The dipole beam forms two separate solitons that repel because of the initial π-phase difference. (c) Output intensity distribution in both components of the dipole-mode vector soliton (molecule of light)—now the two repelling lobes of the dipole are trapped by the fundamental beam. (d) Intensity distribution of the dipole component (u) and the scalar beam (v) before (top) and after (bottom) the collision. The arrow indicates initial transverse velocity of the scalar soliton. Rotation of the dipole component after the interaction is clearly visible. The phase difference between the scalar soliton and the lobe of the dipole was approximately π.

Laguerre-Gaussian (LG_{01}) vortexlike mode and carries angular momentum.[2] The second type of vector soliton originates from trapping of a dipolelike Hermite-Gaussian (HG_{01}) mode by a soliton-induced waveguide.[3] It was recently shown[3] that, contrary to naïve intuition, a radially asymmetric dipole-mode soliton is more stable than a radially symmetric vortex-mode soliton, the latter undergoing a nontrivial symmetry-breaking instability and transforming into a rotating dipolelike structure that resembles two spiraling soliton beams. In fact, the dipole-mode soliton is a robust object that survives collisions with other localized structures, and it can be referred to as a *molecule of light*—a composite state of two simple beams, atoms of light.

Experimental observation of such dipole-mode vector solitons, molecules of light, was recently reported by Krolikowski *et al.*,[4] who used a photorefractive strontium barium niobate (SBN) crystal biased with a dc field of 1.5-2.5 kV to produce an effective saturable self-focusing nonlinearity. Krolikowski *et al.*[4] employed two different methods of producing the dipole component: phase imprinting and with a symmetry-breaking instability of a vortex-mode soliton. Observation of dipole-mode vector solitons in a SBN crystal was also reported by Carmon *et al.*[5]

More recently both theoretical and experimental results confirmed the robust nature of the dipole-mode solitons by observation of various scattering events of scalar spatial solitons and other dipoles on these molecules of light. Many amazing features of these unique objects have been revealed in the inelastic collision processes. These include the excitation of internal oscillatory modes of the molecules of light and the transformation of the linear momentum of an incident atom of light (scalar soliton) into the angular momentum of a dipole-mode soliton (see Fig. 1).

References and Notes

1. G. I. Stegeman and M. Segev, "Optical spatial solitons and their interactions: universality and diversity," Science, **286**, 1518-23 (1999).
2. Z. H. Musslimani, M. Segev, D. N. Christodoulides, and M. Soljacic, "Composite multihump vector solitons carrying topological charge," Phys. Rev. Lett. **84**, 1164-7 (2000).
3. J. J. García-Ripoll, V. M. Pérez-García, E.A. Ostrovskaya, and Yu. S. Kivshar, "Dipole-mode vector solitons," Phys. Rev. Lett. **85**, 82-5 (2000).
4. W. Krolikowski, E. A. Ostrovskaya, C. Weilnau, M. Geisser, G. McCarthy, Yu. S. Kivshar, C. Denz, and B. Luther-Davies, "Observation of dipole-mode vector solitons," Phys. Rev. Lett. **85**, 1424-7 (2000).
5. T. Carmon, C. Anastassiou, S. Lan, D. Kip, Z. H. Musslimani, M. Segev, and D. Christodoulides, "Observation of two-dimensional multimode solitons," Opt. Lett. **25**, 1113-1 5000).

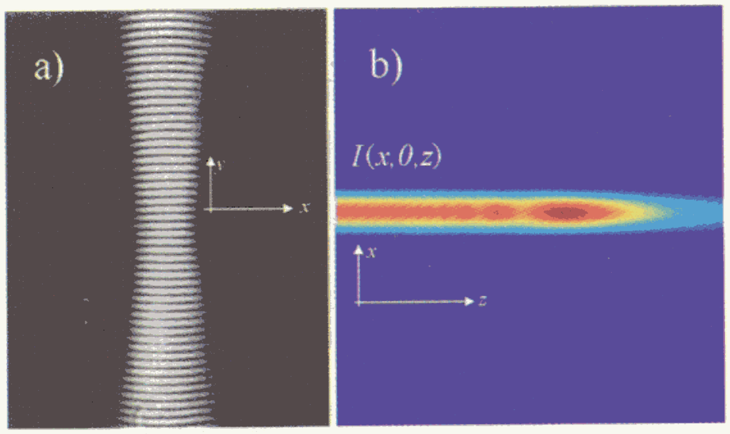
New Member in the Family of Propagation-Invariant Optical Fields: Mathieu Beams

By Julio César Gutiérrez-Vega, Marcelo David Iturbe-Castillo, Eduardo Tepichin, Gustavo Ramírez, Ramon Martin Rodríguez-Dagnino and Savino Chávez-Cerda.

Propagation-invariant optical fields (PIOFs) generate interest because, under ideal conditions, they propagate indefinitely without changing their transverse intensity distribution. Their potential applications in wireless communications, optical interconnections, laser machining, and surgery make them highly useful. However, to create truly invariant optical fields, sources with infinite extent would be needed. Nevertheless, in the real world it is possible to create good approximations of such kinds of fields, and the distance over which they can propagate without significant alteration can range from several millimeters to tens of meters or more.

Beamlike approximations to PIOFs were first demonstrated by Durnin and co-workers,[1] who obtained transverse intensity ringed patterns with a J_0-Bessel profile and thus called them Bessel beams. Since that seminal study, research worldwide has followed by identifying the beams' many peculiar features. For some applications the ringed structure of Bessel beams can be a disadvantage. For this reason it is important to identify other three-dimensional propagating solutions of the wave equation with no ringed structure but with invariance.

Although there have been several related studies showing the possibility for creating PIOFs with different kinds of patterns, the studies have been based on the Cartesian and the circular solutions of the wave equa-



Mathieu Beams Figure 1. Fundamental Mathieu beam. (a) Experimental observation of the transverse intensity pattern of the zero-order Mathieu beam. (b) Simulation of the intensity evolution of a finite Mathieu beam; the panel shows the central part along the plane x-z.

tion.[2,3] In a recent paper, based on the McCutchen theorem,[4] Gutiérrez-Vega *et al.* demonstrated theoretically that in elliptic cylindrical coordinates it is possible to create PIOFs.[5] In that study the corresponding Hankel-Mathieu solutions of the Helmholtz equation were used to describe what we called Mathieu beams. Similar to plane waves and Bessel beams, the Mathieu beams also form an orthogonal and complete set in the sense that any propagation-invariant optical field can be represented as the superposition of Mathieu beams.[2,3]

Building on the theoretical research of Ref. 5, we have been able to produce approximations to the zero-order Mathieu beam experimentally. To create them, we identified the corresponding angular spectrum and observed that it can be approximated in the laboratory by an annular slit illuminated with a strip pattern with a Gaussian profile produced, for instance, with the help of a cylindrical lens.[5]

Fig. 1 shows the pattern obtained in the laboratory that propagated almost invariantly for up to 15 m. Fig. 1(a) shows the transverse pattern of the Mathieu beam, whereas Fig. 1(b) shows the simulation of the intensity evolution in the x-z plane corresponding to the central oval. It is important to note that at the sides of the pattern, although no light is apparent, field components that interfere destructively exist in that region. These field components are those that keep the pattern invariant in directions parallel to the x axis, as observed in Fig. 1(b). Our experimental results are in excellent agreement with the theoretical predictions. Also, our investigations show that it is possible to create propagation-invariant higher-order Mathieu beams with elliptic-ringed transverse patterns.

References

1. J. E. Durnin, J. J. Miceli, and J. H. Eberly, "Diffraction-free beams," Phys. Rev. Lett. **58**, 1499-501 (1987).
2. V. Kettunen and J. Turunen, "Propagation-invariant spot arrays," Opt. Lett. **15**, 1247-9 (1998).
3. R. Piestun and J. Shamir, "Generalized propagation-invariant wave fields," J. Opt. Soc. Am. A **15**, 3039-44 (1998).
4. G. Indebetouw, "Nondiffracting optical fields: some remarks on their analysis and synthesis," J. Opt. Soc. Am. A **6**, 150 (1989).
5. J. C. Gutiérrez-Vega, M. D. Iturbe-Castillo, and S. Chávez-Cerda, "Alternative analytic formulation for invariant optical fields: Mathieu beams," Opt. Lett. **25**, 1493-5 (2000).

QUANTUM OPTICS

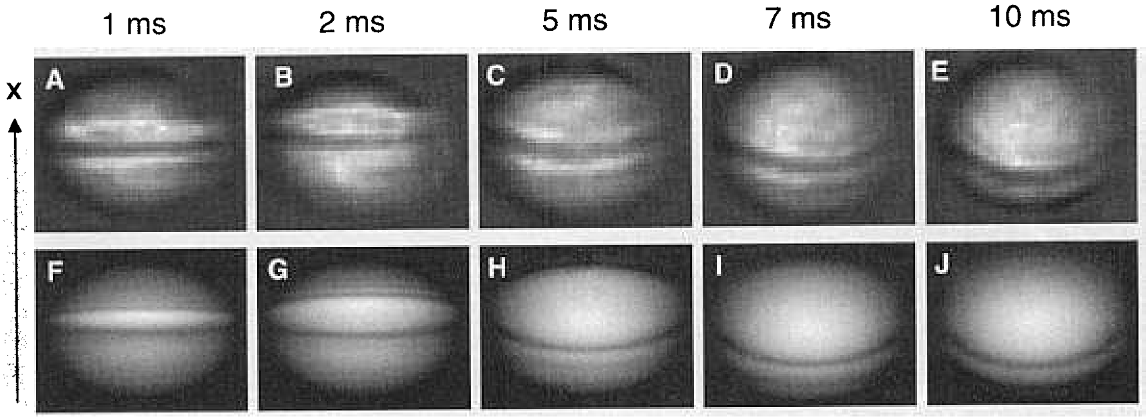
Solitons in a Bose-Einstein Condensate

By David L. Feder

The recent observation of Bose-Einstein condensation (BEC) in weakly interacting gases[1] has opened the door to the field of coherent matter-wave optics. BEC occurs when a macroscopic number of particles obeying Bose statistics occupy a single quantum state. This coherent occupation of the ground state in the atomic trap is analogous to the many photons in the cavity of a single-mode laser. The weak (but nonnegligible) interactions between atoms, however, modify the structure of the occupied mode and introduce nonlinearity into the system.

When the many-atom state is treated within a mean-field approximation, a nonlinear term arises in the equations of motion for the condensate wave function. The resulting nonlinear Schrödinger equation is formally similar to that describing the propagation of light in

Solitons in a Bose-Einstein Condensate Figure 1. Experimental (A-E) and theoretical (F-J) images of the integrated condensate density for various times after the phase imprint. Because the imaging technique is destructive, each frame shows a different condensate.



Guiding Mechanism in Photonic Crystal Fibers, Albert Ferrando, Enrique Silvestre, Juan José Miret, and Pedro Andrés, Departament d'Òptica, Universitat de València, Burjassot, Spain, Miguel V. Andrés, Institut de Ciència dels Materials, Universitat de València, Burjassot, Spain.

Nonlinear Localized Modes in Photonic Crystal Waveguides, Serge F. Mingaleev, Bogolyubov Institute for Theoretical Physics, Kiev, Ukraine, Yuri S. Kivshar, Optical Sciences Centre, Australian National University, Australia, Rowland A. Sammut, School of Mathematics and Statistics, Australian Defence Force Academy, Australia.

Propagating Fields

Modulation Instability of Spatially Incoherent Light Beams and Pattern Formation in Incoherent Wave Systems, Detlef Kip,[1,2] Marin Soljacic,[1,3] Mordechai Segev,[1,4]: (1) Physics Department and Solid State Institute, Technion, Haifa 32000, Israel, (2) Physics Department, Universität Osnabrück, Osnabrück, Germany, (3) Physics Department, Princeton University, Princeton, NJ, (4) Department of Electrical Engineering, Princeton University, Princeton, NJ and Evgenia Eugenieva and Demetrios N. Christodoulides, Electrical Engineering and Computer Science Department, Lehigh University, Bethlehem, PA.

Generation of Optical Spatiotemporal Solitons, Xiang Liu, Kale Beckwitt, and Frank Wise, Department of Applied Physics, Cornell University, Ithaca, NY.

Light Molecules: Dipole-Mode Vector Solitons, Wieslaw Krolikowski, Barry Luther-Davies, Glen McCarthy, and Matthias Geisser, Laser Physics Centre, Australian National University, Australia, Yuri Kivshar and Elena Ostrovskaya, Optical Sciences Centre, Australian National University, Australia, Carsten Weilnau and Cornelia Denz, Institute of Applied Physics, Darmstadt University of Technology, Darmstadt, Germany, Juan J. García-Ripoll and Victor Pérez-García, Department of Mathematics, Universidad de Castilla-La Mancha, Spain.

New Member in the Family of Propagation-Invariant Optical Fields: Mathieu Beams, Julio C. Gutiérrez-Vega, Marcelo D. Iturbe-Castillo, Eduardo Tepichin, Gustavo Ramírez, and Sabino Chávez-Cerda, Instituto Nacional de Astrofísica, Optics y Electrónica (INAOE), Puebla, Mexico, and Ramon M. Rodríguez-Dagnino, Instituto Tecnológico de Estudios Superiores de Monterrey (ITESM), Monterrey, Mexico.

Quantum Optics

Solitons in a Bose–Einstein Condensate, David L. Feder, National Institute of Standards and Technology, Gaithersburg, MD, and the University of Oxford, Oxford, UK.

Quantum Switch, Byoung S. Ham, Center for Quantum Coherence and Ultrafast Information Communications, Electronics and Telecommunications Research Institute, Korea.

Quantum Wells Coupled by Light: Eigenmode Dynamics in Resonant Rayleigh Scattering, Claudia Ell, Bernhard Grote, Galina Khitrova, Hyatt M. Gibbs, and Stephan W. Koch, Optical Sciences Center, University of Arizona, Tucson, AZ, John P. Prineas, and Jagdeep Shah, Bell Laboratories, Lucent Technologies, Holmdel, NJ.

Spectral Imaging

Reconstruction of Fiber Gratings by Use of Time-Frequency Signal Analysis: Application to Distributed Sensing, José Azaña and Miguel A. Muriel, Grupo de Señal Fotónica. E.T.S.I. Telecomunicación, Universidad Politécnica de Madrid, Madrid, Spain.

Diffraction Resolution Barrier Fundamentally Broken in Far-Field Fluorescence Microscopy, Stefan W. Hell and Thomas A. Klar, Max-Planck-Institute for Biophysical Chemistry, High Resolution Optical Microscopy Group, Göttingen, Germany.

Metal Nanoparticles for Spectrally Coded Optical Data Storage, Harold Ditlbacher, Joachim R. Krenn, Bernhard Lamprecht, Alfred Leitner, and Franz R. Aussenegg, Institute for Experimental Physics, Karl-Franzens-University of Graz and Erwin-Schrödinger-Institute for Nanoscale Research, Graz, Austria.

Spectroscopy

Remote Measurements of Volcanic Gases with a Diode-Laser-Based Spectrometer, Livio Gianfrani, Dipartimento di Scienze Ambientali della Seconda Università di Napoli, Caserta, Italy, and Paolo De Natale, Istituto Nazionale di Ottica Applicata, Firenze, Italy.

Ultrafast Technology

Ultrafast All-Optical Switching Based on Intersub-Band Transition in GaN/AlGaN and InGaAs/AlAsSb Multiple Quantum Wells, Osamu Wada, Haruhiko Yoshida, Teruo Mozume, Arup Neogi, Nikolai Gergiev, Tomoyuki Akiyama, and Kiyoshi Asakawa, FESTA Laboratories, The Femtosecond Technology Research Association, Tsukuba, Japan, and Nobuo Suzuki, Norio Iizuka, and Kei Kaneko, Corporate Research and Development Center, Toshiba Corporation, Kawasaki, Japan, Takashi Asano and Susumu Noda, Department of Electrical Science and Engineering, Kyoto University, Kyoto, Japan.

Terahertz Transceiver, Qin Chen and X.-C. Zhang, Department of Physics, Applied Physics, and Astronomy, Rensselaer Polytechnic Institute, Troy, NY.

Melting Metals with Ultrafast Optical Excitation, Chunlei Guo, George Rodriguez, Ahmed Lobad, and Antoinette J. Taylor, Condensed Matter and Thermal Physics Group, Materials Science and Technology Division, Los Alamos National Laboratory, Los Alamos, NM.