



**Annual Report
Institute of Applied Physics**

2005



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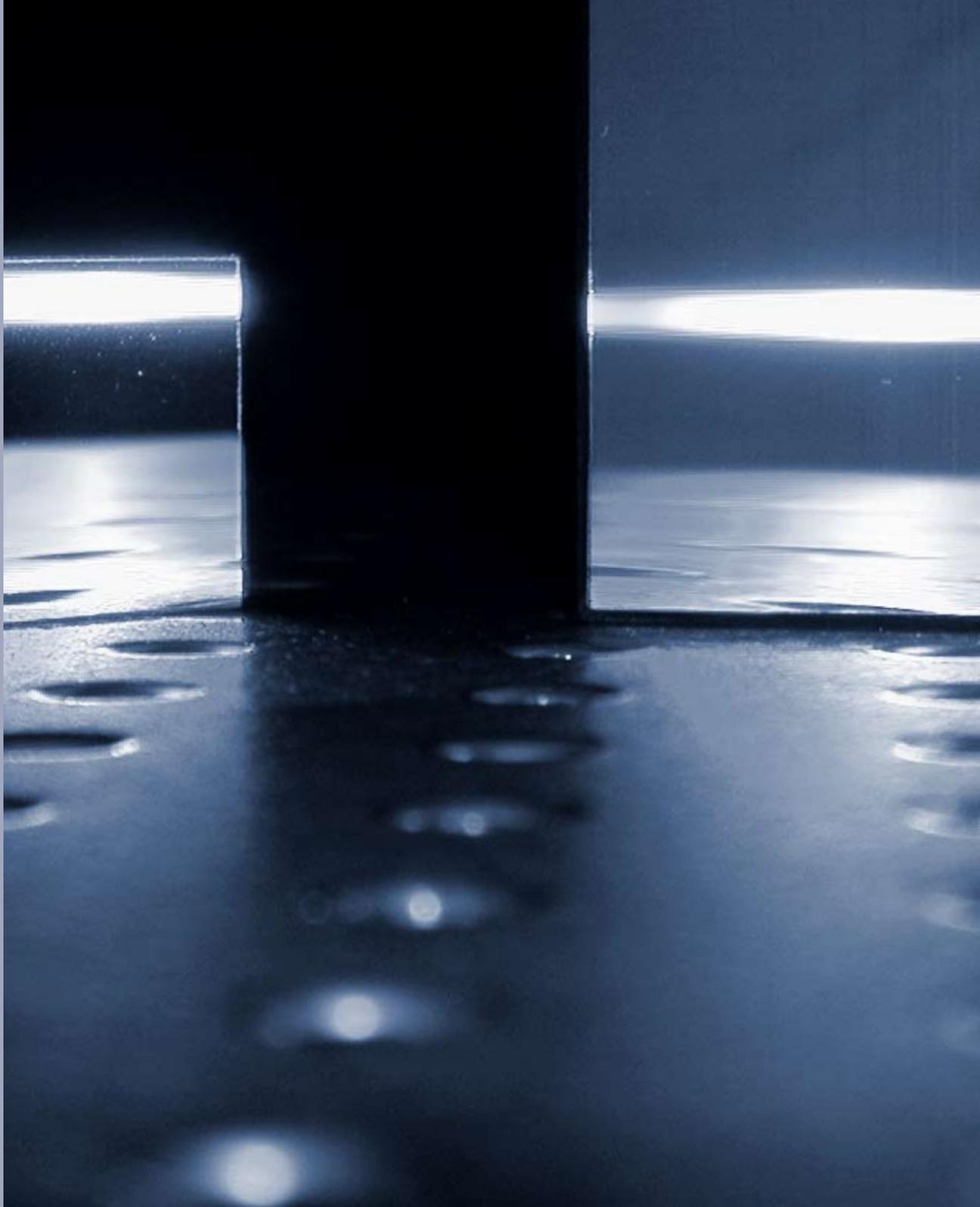
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Foreword



■ **Dear reader,**

2005 – the Einstein year. In 2005 the 100th anniversary of Einstein's theory of relativity and the 50th anniversary of this world-famous scientist's death were celebrated. UNESCO celebrated the international »World Year of Physics« for the same reason. According to a representative survey, Einstein is known to nearly 75 percent of the German population. Einstein was a »pop star« of science in his era and remains so today.

The public associates Einstein with the theory of relativity, but he is also the physicist who was able to develop a precise description of the interaction between light and matter. In fact, it was his work on the photo-electric effect which was awarded the Nobel Prize. Einstein's description of the absorption and emission of light was the theoretical foundation for the amplification of light and ultimately the laser which is an indispensable tool in our laboratories at the Institute for Applied Physics (IAP) at the Friedrich Schiller University of Jena and the Fraunhofer Institute for Applied Optics and Precision Mechanics (IOF).

Today we use the laser for the recording and playback of information, process control and inspection and, not least, for the precise structuring and joining of materials and components. Currently at the IAP, prominent examples regarding the application of lasers include developments in the fields of laser based projection systems, ultra precision machining; high-lights at national and international fairs such as the World of Photonics – Laser 2005 Munich.





However, the laser itself is still a research topic at the IAP and the IOF. Using this methodology, our laboratories were able to develop today's most powerful ultra short pulse laser with output powers of more than 100 W. This fiber laser system represents the first ultra short pulse laser for so-called real-world applications. Together with our partners in science and industry we are currently preparing these lasers for applications in industrial manufacture and medicine.

Development projects such as these illustrate particularly well the advantages of the close collaboration between the university and the Fraunhofer Institute. Only through the mastery of the fundamental principles of laser-matter-interaction on the one hand, and the competence regarding optical systems on the other hand, will the IOF/IAP be able to continually reinforce their position as a competent partner for science and industry in the area of optics/photonics. In this context, I was particularly pleased about the award of the Gottfried-Wilhelm-Leibniz-Preis 2005; the highest award for science in Germany, as it confirms that both our approach and direction are sound.

Key components in modern optical systems are increasingly based on micro and nano-optics with complete functionality and this is also reflected in our work. The establishment of the Center for Innovation Competence ultra optics and the merging of expertise in the manufacture of micro and nano-scale optics, together with measurement and testing devices at the Center for Micro- and Nano-optics (CMN-optics), have broadened the development potential for our partners in science and industry. Complete solutions, from the design to the manufacture of the components, are offered. The technological foundations of the CMN-optics are the electron beam exposure system, laser-lithography, ultra precision diamond turning, and state-of-the-art replication technologies.

I would like to thank our partners in industry and science for their excellent cooperation and the Federal Ministry of Education and Research, the Thuringian Ministry of Education and Cultural Affairs and the Deutsche Forschungsgemeinschaft for their continued support.

My particular respect, my acknowledgements and my thanks go to my co-workers for their excellent work and their commitment. Their work is the foundation for the continuous, further development of the IAP and the IOF.

Jena, February 2006



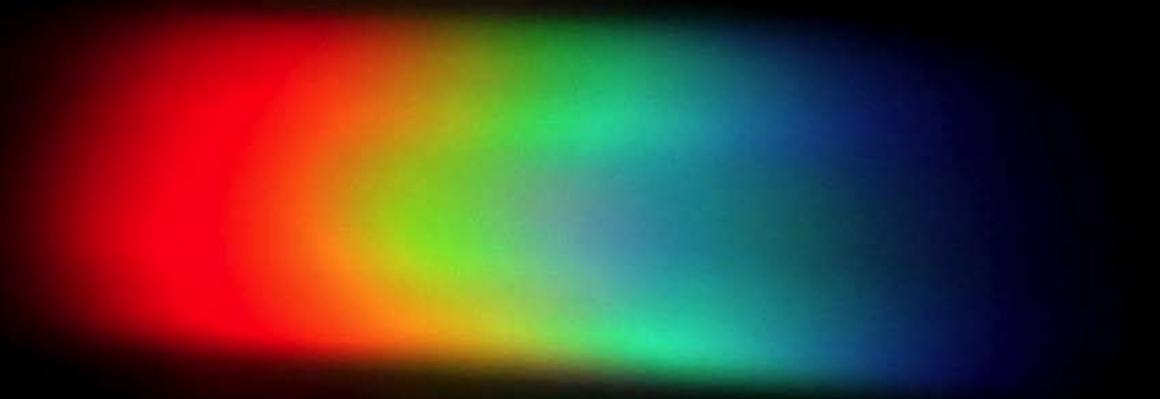
Prof. Dr. Andreas Tünnermann

Director of the Institute of Applied Physics





The Institute



■ Research Profile

The Institute of Applied Physics at the Friedrich-Schiller-University Jena has a longstanding tradition and competence in design, fabrication and application of active and passive photonic elements for both, optic and optoelectronic devices. A total staff of 30 scientists and engineers are working presently in education and R&D. In addition, more than 20 diploma and PhD students and visiting scientists are researching at the IAP.

The institute has a floorspace of 1,200 m² with installed clean rooms and optical laboratories including microstructure technology (electron beam and photo lithography, reactive ion and reactive ion beam etching, diffusion and ion exchange ovens, coating facilities, scanning electron and atomic force microscopy) and optic / optoelectronic testing and measuring instrumentation.

Research Fields

The Institute of Applied Physics at the Friedrich-Schiller-University Jena is engaged in the development of:

- All solid state lasers
- Amplitude and phase masks
- Calibration tools
- Electro-optical materials
- Fiber and waveguide lasers and amplifiers
- Integrated optical devices
- Advanced micro- and nano-processing technology
- Microoptics (refractive / diffractive)
- Nanooptics
- Nonlinear optical devices
- Physical optical elements

for optical information and communication technology, medicine and biology, process technology including material processing and optical measurement techniques.





■ Staff Members

Tünnermann, Andreas Prof. Dr.
Head of the Institute

Abbe, Sylvia
Aichele, Tilo Rolf Dr.
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Gründer, Hans-Georg
Hartung, Holger
Häußler, Sieglinde
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Käsebier, Thomas
Kaless, Antje

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Technology & Microoptics
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Leitel, Robert
Liem, Andreas Dr.
Limpert, Jens Dr.
Head of Fiber & Waveguide Lasers
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Nolte, Stefan Dr.
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Onishchukov, Georgy Dr.
Head of Optical Communication
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Otto, Christiane
Pertsch, Thomas Prof. Dr.
Head of Nano Optics
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Pradarutti, Boris
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Wikszak, Elodie
Wilbrandt, Steffen
Will, Matthias Dr.
Wirth, Christian
Wittig, Lars-Christian
Wyrowski, Frank Prof. Dr.
Head of Optical Engineering
Zellmer, Holger Dr.
Head of Fiber &
Waveguide Lasers

Guests

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Cherianath Prof.
Indien
Chen Prof.
Taiwan
Haeffelin, Scott
USA
Hsu, Kuel-Chu
Taiwan
Krogh-Nielsen, Carsten
Dänemark
Kruger, Andrew
USA
Nejadmalayeri, Amir Hossein
Univ. of Toronto, Kanada
Tervo, Jani Dr.
Univ. Of Joensuu, Finland





■ Lectures · Seminars · Conferences

Lectures

- V Atom- und Molekülphysik
- S Atom- und Molekülphysik
- V Technische Thermodynamik
- V/S Grundlagen der wellenoptischen Simulationstechnik
- V Optik ultrakurzer Pulse
- V Computational physics in oprics
- V Mikrostrukturtechnik für Mikro- und Nanooptik
- S Theoretische Optik
- WV Grundlagen der Laserphysik und optischen Spektroskopie
- WV Optik mit Matlab
- WV Integrierte Optik
- WV Grundlagen der Nano- und Mikrostrukturtechnik
- WS Grundlagen der Laserphysik und optischen Spektroskopie
- WS Photon Management
- WV Physikalische Optik im Simulationsexperiment I
 - P Optikexperimente im virtuellen Labor
- WV Mikrostrukturtechnik für Mikro- und Nanooptik
 - P Physikalisches Praktikum Nebenfach

Seminars

- Seminar:
 - Angewandte Photonik
- Institutsseminar:
 - Angewandte Physik
- Bereichsseminar:
 - Mikrostrukturtechnik
- Bereichsseminar:
 - Nanooptik

Conferences

- Optical Systems Design Jena, 2005
- DGaO Sommerschule, 2005

Explanations

- V lecture
- S seminar
- P practical training
- WV optional lecture
- WS optional seminar
- WP optional practical training

■ Diploma Theses · Doctoral Theses · Habilitation

Diploma Theses

Martin Bischoff

Design und Herstellung gechirpter Spiegel zur Kontrolle von fs-Pulsen

Dominik Blömer

Nichtlineare Effekte in Femtosekunden-Laser geschriebenen Wellenleitern

Dimitri Heumann

Untersuchung der Messauflösung eines phasogrammetrischen Mehrbild-3D-Digitalisierers

Bernd-Jürgen Meyer

Untersuchungen zur Erzeugung von CO₂-Laserpulsen im Mikroskundenbereich bei höchster Strahlqualität und deren Anwendung in der Materialbearbeitung

Raik Petrasch

Entspiegelung optischer Oberflächen auf Basis selbstorganisierender Nanostrukturen

Jörg Petschulat

Herstellung, Charakterisierung und theoretische Behandlung von metallbeschichteten Mottenaugenstrukturen

Daniela Radtke

Theoretische und experimentelle Untersuchungen an Speckle-Verschiebungssensoren

Sebastian Schlichting

Theoretische und experimentelle Untersuchungen zur Erzeugung nanoskaliger Pulver mittels CO₂-Laserverdampfung





Frank Setzpfandt

Entwicklung eines Messverfahrens zur Bestimmung der Dispersionsrelation von Wellenleitern in Photonischen Kristallen

Damian Schimpf

Application of Supercontinuum to Spectroscopy

Oliver Schmidt

Aufbau und Charakterisierung eines Kurzpulsfaseroszillators

Max Stumpf

Pulsformierung in modengekoppelten Faserszillatoren

Stefan Walter

Effizienzsteigerung diffraktiver optischer Elemente mittels Strukturierung auf entspiegelten Substraten

Doctoral Theses

Markus Augustin

Optik in photonischen Kristallen mit niedrigem Brechzahlkontrast

Henrik Banse

Laserstrahlloten – Technologie zum Aufbau optischer Systeme

Alexander Büttner

Untersuchung experimenteller Verfahren zur resonatorinternen Modenformung

Jacques Duparré

Microoptical Artificial Compound Eyes

Petra Heger

Spektrale Eigenschaften nanostrukturierter dielektrischer und metallischer Dünnschichtsysteme

Christian Mühlig

Zur Absorption gepulster ArF-Laserstrahlung in hochtransparenten optischen Materialien

Peter Triebel

Wechselwirkung von Licht mit periodischen metallischen Strukturen

Matthias Will

Ultrakurzpulsinduzierte Brechzahlmodifikationen in transparenten Festkörpern

Lars-Christian Wittig

Kontinuierliche Oberflächenprofile zur optischen Strahlformung

Hagen Zimer

Leistungskalierung nicht-planarer monolithischer Ringlaser

Habilitation

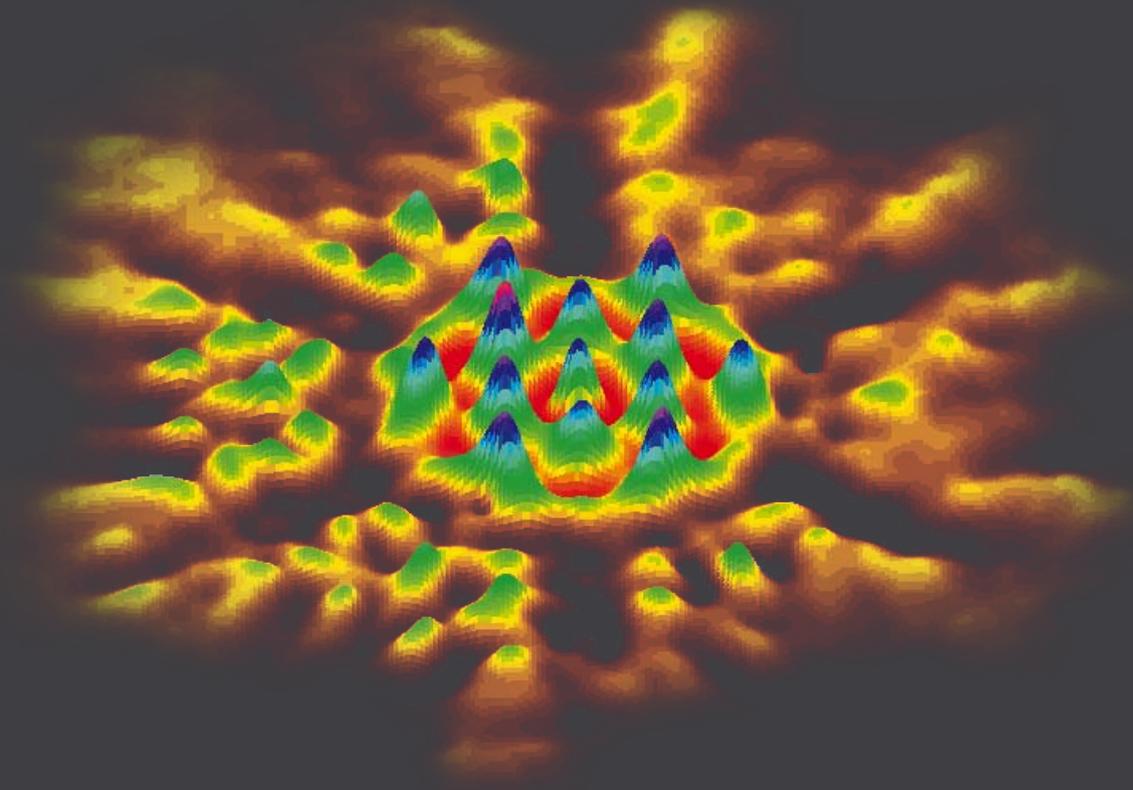
Dr. (Rus) Georgy Onishchukov

Semiconductor optical amplifiers in optical communications systems

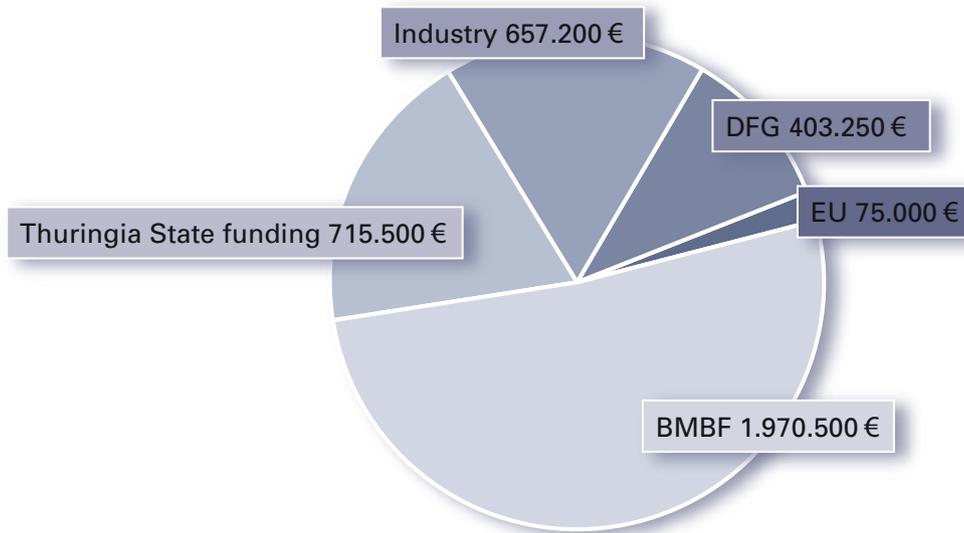




Projects



■ Statistic



■ Externally Funded Projects

DFG-funding

SFB Transregio: Gravitationswellenastronomie

(Project term: 1/2003 – 12/2006)

2005: 63.250,00 €

Photonische Kristalle, TV:

Low-index sandwich photonic crystals for linear and nonlinear applications

(Project term: 6/2003 -5/2005)

2005: 40.000,00 €





Monolithische Integration photonischer Bauelemente auf Basis der Flüssigphasenepitaxie (SPP: Integrierte elektrokeramische Funktionsstrukturen)

(Project term: 11/2003 – 10/2007)

2005: 115.000,00 €

Nichtlineare-raumzeitliche Dynamik in dissipativen und diskreten optischen Systemen (Zentralprojekt)

(Project term: 3/2004 – 6/2007)

2005: 14.000,00 €

Dimensionseffekte in diskreten Systemen (Teilprojekt)

(Project term: 3/2004 – 6/2007)

2005: 40.000,00 €

3D mikro- und nanostrukturierte Optik

(Project term: 1/05 – 12/06)

2005: 63.000,00 €

Gottfried Wilhelm Leibniz Programm

(Project term: 11/05 – 10/2010)

2005: 15.000,00 €

Neue Strategien der Mess- und Prüftechnik für die Produktion von Mikrosystemen und Nanostrukturen – NanoStreu

(Project term: 10/2004 – 9/2006)

2005: 53.000,00 €

TMWFK-funding

OPTOMATRONIK: Integriert-optische Systemtechnik: Konzeption, Darstellung und Charakterisierung mikro- und nanostrukturierter optischer Elemente

(Project term: 4/2002 – 3/2005)

2005: 55.000,00 €

OPTOMATRONIK: Integriert-optische Systemtechnik: Konzeption, Darstellung und Charakterisierung mikro- und nanostrukturierter optischer Elemente -

Strukturtransfer

(Project term: 10/2004 – 12/2005)

2005: 660.500,00 €

BMBF-funding

Photonische Kristallfasern für neuartige Lichtquellen mit steuerbarer Funktionalität – TV: Nanostrukturierte Wellenleiter zur Erzeugung und Führung hoher Leistungsdichten (PHOFAS)

(Project term: 6/2002 – 5/2005)

2005: 96.500,00 €

CoOp: Verbundprojekt Hybride Integrationstechnologie für kompakte, funktionale und fertigungstaugliche optische Module, TV: 3D-Lithografie

(Project term: 5/2004 – 9/2005)

2005: 90.000,00 €

Neue Herstellungsverfahren für tageslichttaugliche Bildschirmhologramme (NHTB), TV: Design und Technologieentwicklung für holografietaugliche Strahlformungselemente (NHTB)

(Project term: 7/2003 – 6/2006)

2005: 140.000,00 €





Zentrum für Innovationskompetenz ULTRAOPTICS:

Design und Realisierung hochfunktioneller optischer Metamaterialien durch Nanostrukturierung sowie deren Anwendung in komplexen photonischen Systemen

(Project term: 4/2005 – 3/2010)

2005: 1.200.000,00 €

PROMPTUS Verbundprojekt: Produktive Mikro-Prozeß-Technik mit ultrakurzgepulsten Strahlquellen, TV: Ultrakurzpuls-Faserverstärker hoher Leistung

(Project term: 5/2005 – 4/2008)

2005: 145.000,00 €

Kopfchirurgisches Zentrum, TV: Minimalinvasive Femtosekunden-Laserchirurgie an der Augenlinse

(Project term: 9/2005 – 8/2008)

2005: 207.000,00 €

Lateralstrukturierung dielektrischer Schichten

(Project term: 1/2004 – 6/2005)

2005: 25.000,00 €

Thermo-optisches Design von Hochleistungfaserverstärkern
(UA: Thermo-optische Analyse von Faserverstärkersystemen)

(Project term: 7/2004 – 4/2006)

2005: 67.000,00 €

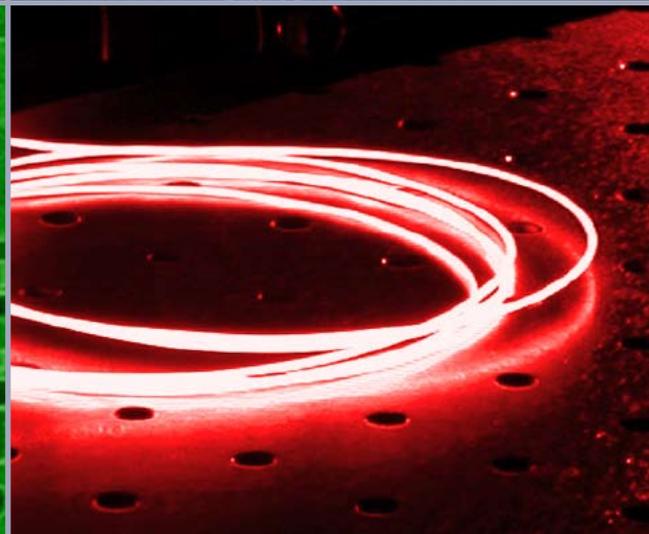
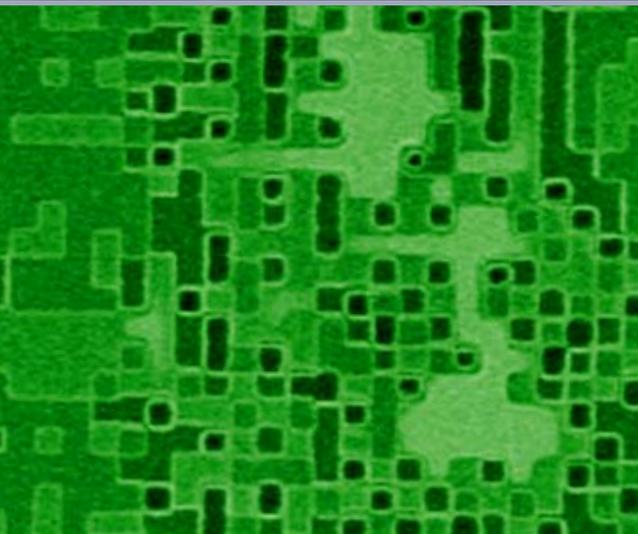
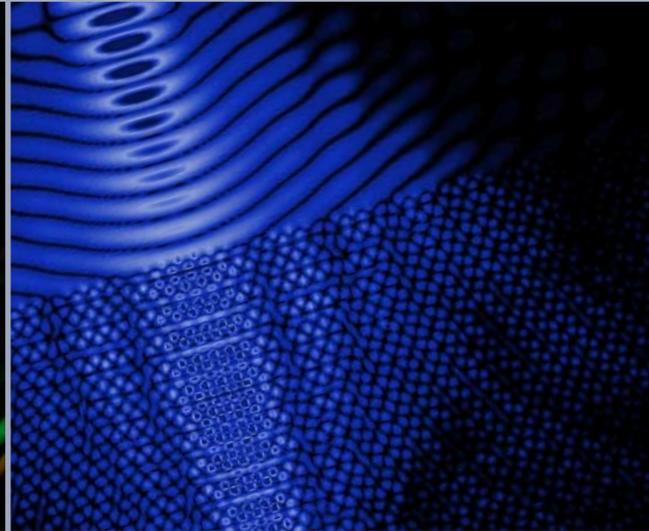
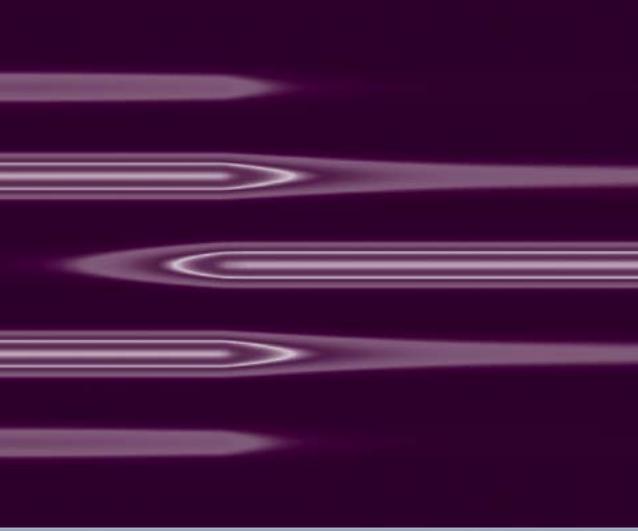
EU-funding

3D-Nanoprint (079010/23)

(Project term: 1/2005 – 12/2006)

2005: 75.000,00 €

Industry & sub-contracts: 657.200,00 €



Achievements & Results



Achievements & Results

■ Microstructure Technology
& Microoptics

■ Ultrafast Optics

■ Nano Optics

■ Friedrich-Schiller-University Jena
Institute of Applied Physics
Beutenberg Campus
Albert-Einstein-Straße 15
D-07745 Jena

■ Fiber & Waveguide Lasers

■ Optical Engineering



Achievements & Results



■ Microstructure Technology & Microoptics

Color picture generation by RGB-holograms

Ernst-Bernhard Kley

The generation of pictures by projective techniques can be very useful, if the picture can not be created in the image plane itself. The common projection techniques, which modulate a beam of light by means of an LCD- or microlens-array, are restricted regarding the achievable picture deformation (important for projection on tilted surfaces) and the size of the projection unit itself. Therefore conventional projection systems can not be used for certain applications.

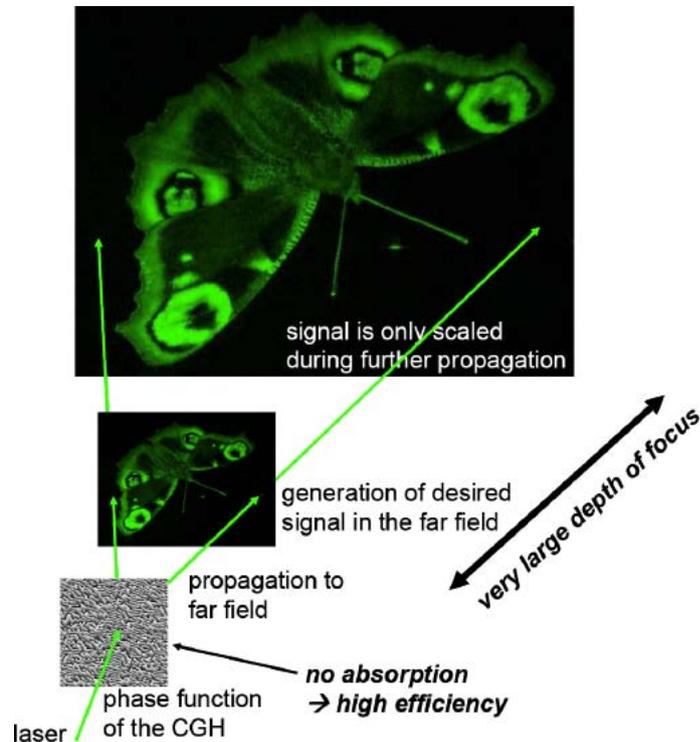
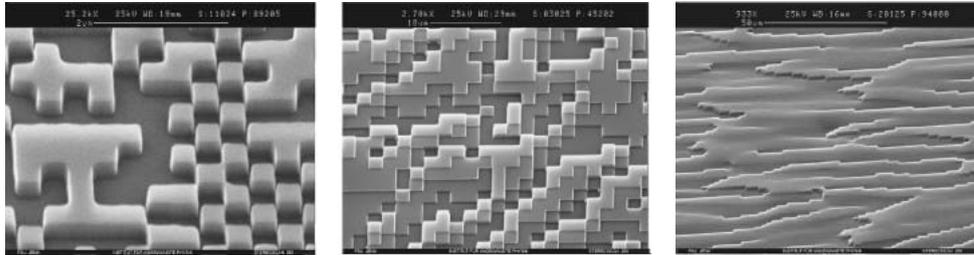


Figure 1: principle of a computer generated hologram (CGH)



binary

multi level

continuous

Figure 2: SEM pictures of fabricated holograms

In this context the institute of applied physics currently develops computer generated RGB holograms, which allow the realization of projection systems with a large depth of focus and high contrast. Furthermore this principle allows very small projection units, if the necessary laser power is available (e.g. delivered by an optical fiber).

The generation of monochromatic images by computer generated holograms (CGH) is common knowledge. An optical function is modulated onto a laser beam, creating the desired picture by interference during the further propagation of the beam (fig. 1). In principle the CGH and the image plane are connected by a fourier transform, therefore CGHs show the typical properties of conventional holograms (tolerant to adjustment errors, ›broken‹ holograms still create the whole image). In the most general case, a hologram can influence both amplitude and phase. However, in our case mainly phase holograms are of interest because of their superior efficiency.

To fabricate CGHs in fused silica, electron beam lithography or laser beam writing – depending on the minimal structure size - in combination with reactive ion beam etching is applied (fig. 2). It is possible to build binary CGHs, which are comparably easy to fabricate but always create a mirror image and have thus a maximal efficiency of 50%, or to put more effort to the fabrication and use multi-level or continuous lithographic techniques, which results in more efficient elements (up to 80-90%), creating also an even clearer signal.



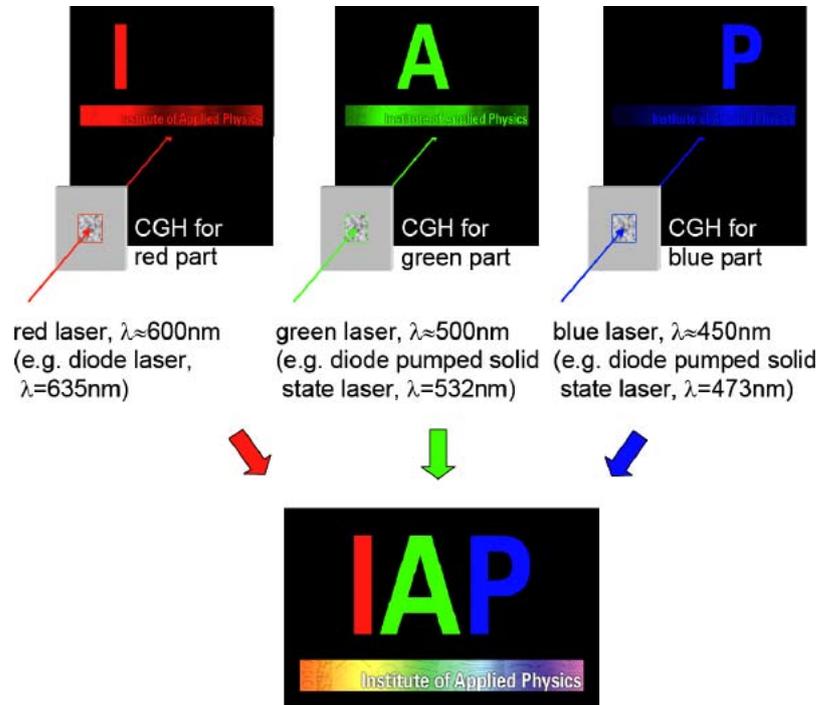


Figure 3: principle of creating a color picture by three CGHs

To create colored pictures three holograms are necessary, which encode the red, green and blue part of the image separately. The illumination of these three holograms with the corresponding wavelengths allows the creation of three pictures in the main colors red, green and blue, which create a fully colored picture if they are superimposed correctly (fig. 3). To ensure the right color-balance, the single elements must diffract the right amount of light to the RGB-parts of the image. To this end we developed for the case of binary holograms a new concept of 'reduced' pixels, which means that the pixels are smaller than usual, resulting in an increased zeroth diffraction order and a reduced intensity of the created image. The correlation between the amount of pixel reduction and signal intensity was investigated and used to create color CGHs that can project different images with the right color balance without adjusting the laser intensities.

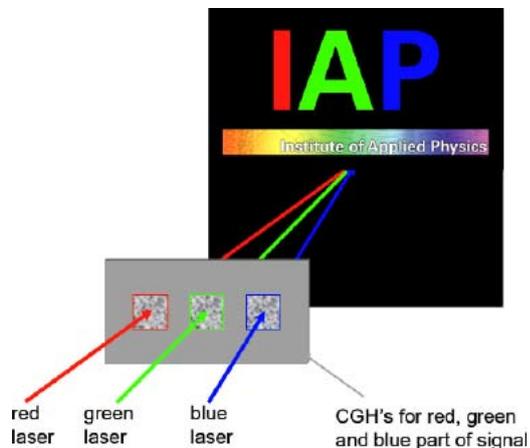


Figure 4: principle of lateral color multiplexing

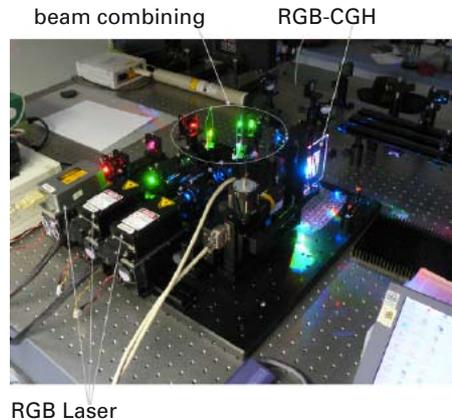


Figure 5: experimental projector unit

with lateral color multiplexing

For the multiplexing of the three wavelengths in the element plane, allowing to create a full color image by CGHs exist two principally different methods, which are described in the following:

1. Lateral Color Multiplexing (CGHs are placed side by side)

The simplest way of separating the colors in the hologram plane is to laterally separate the three CGHs (fig. 4). This can be done on three separate substrates that are placed directly behind each other with the necessary lateral offset, or by structuring one substrate with all 3 CGH. The latter option allows an easier handling in the optical setup but reduces the efficiencies for at least two wavelengths, since the etch depth is the same for all three elements. However, with some technological effort (selective covering during the etch process) this disadvantage can be overcome. To demonstrate the capability of this approach, a portable projection unit was developed (fig. 5). It uses two diode-pumped solid-state lasers for the generation of the blue (250mW @ 473nm) and green (250mW @ 532nm) parts of the picture and one segmented diode laser (300mW @ 635nm) for the red parts. The created pictures are in good agreement with the design. They are





Design



Measurement

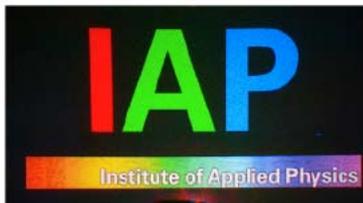


Figure 6:
experimental results
for lateral color multiplexing

very colorful due to the used laser wavelengths and exhibit a high contrast (fig. 6). However one important advantage of CGHs is lost in the case of lateral color multiplexing, that is the correct superposition of all three colors can only be obtained for a certain image plane, which reduces the depth of focus.

2. Longitudinal Color Multiplexing (CGHs are placed in a row)

The reason for trying to develop color CGHs with longitudinal color multiplexing is to avoid the lateral displacement of the single red, green and blue CGHs. Three CGHs that are on axis with the laser beam and have just a negligible longitudinal displacement would allow the creation of color pictures from one white laser beam (combined from red, green and blue) (fig. 7). Such an RGB-CGH would have the same advantages as a conventional CGH (large depth of focus, very easy handling). To achieve the wavelength separation, a combination of Bragg mirrors

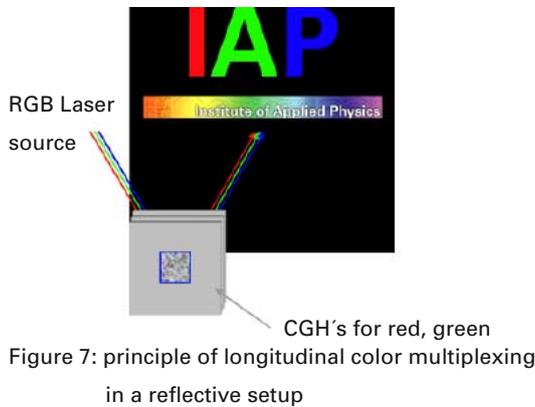


Figure 7: principle of longitudinal color multiplexing in a reflective setup

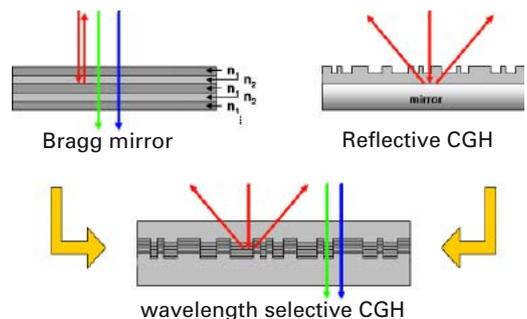


Figure 8: principle of a wavelength selective CGH

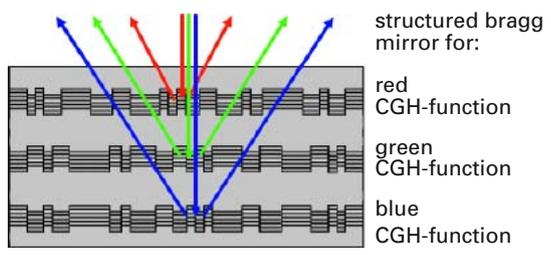


Figure 9: principle of stacked, buried Bragg-gratings as RGB-CGH

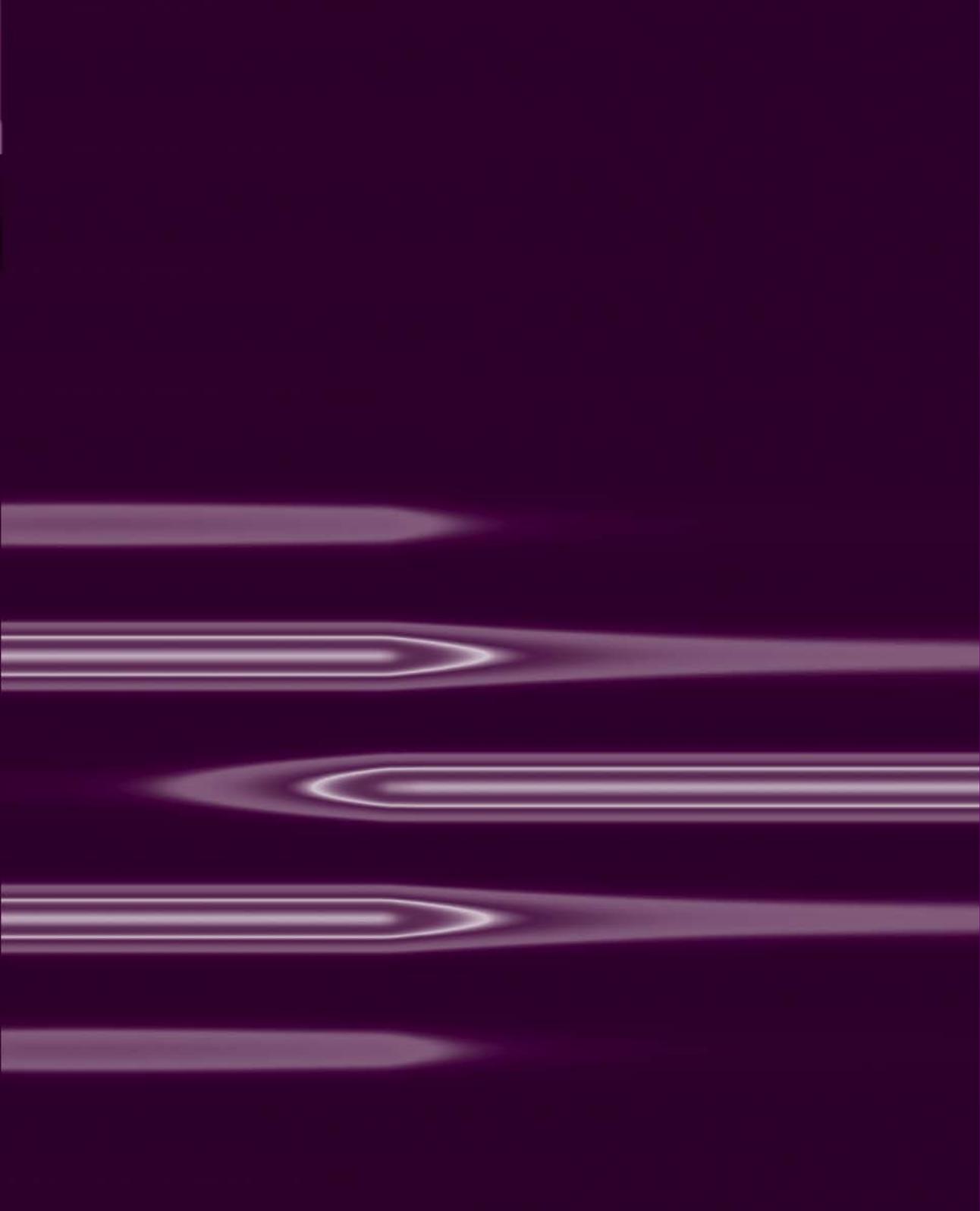
(mirrors, composed of several layers of dielectric materials with different refractive index) and conventional phase-CGHs was used. The Bragg mirror, designed to reflect only one of the three wavelengths and transmitting the others, is applied to a CGH, designed to create the desired image in a reflective setup. If such a structured Bragg mirror is furthermore buried in one and the same material, so that the refractive index on both of its sides is the same, it is possible to encode the CGH information to one of the wavelengths, while the other two pass the structure unaffected (fig. 8). Stacking three such elements, designed for the three separate wavelengths on top of each other result in the desired wavelength selective RGB-hologram (fig. 9). To demonstrate this principle, we subsequently used molding techniques to impress the CGH functions to PMMA (in cooperation with Fraunhofer-IOF) and applied Bragg-mirrors by sputtering (in cooperation with MSO Jena GmbH). The resulting element was illuminated using the abovementioned optical setup, but this time with a collimated, ›white‹ laser beam; on axis



combined from red, green and blue. The resulting image is again in very good agreement with the design; it's very colorful and sharp. However, ›ghost‹ pictures appear, that means monochromatic images that are smaller or bigger than the RGB image become visible (fig. 10). This is due to the influence, the structuring of the Bragg mirror has on its wavelength selectivity. The effect gets worse with decreasing pixel size, because rounding effects during the sputtering of the Bragg mirrors dielectric layers become more important to the optical function. As a result every Bragg mirror reflects also a part of wavelengths it is not designed for. We are currently investigating how to improve the wavelength selectivity of structured Bragg mirrors without decreasing their optical functionality as a CGH.



Figure 10: Experimental result for longitudinal color multiplexing



Achievements & Results



■ Ultrafast Optics

Nonlinear localization in femtosecond laser written waveguide arrays in fused silica

Stefan Nolte

Modern communication systems are based on integrated optical devices to control the properties of light in all-optical networks. Within the past 10 years a novel technique for the direct writing of photonic structures based on focusing femtosecond optical pulses into the bulk of a transparent material has been demonstrated. Due to the high energy densities in the focal region multi-photon absorption occurs leading to a localized change of the material's (optical) properties. By moving the sample with respect to the focus a continuous region with modified refractive index can be created. With this powerful technique it is possible to fabricate permanent three-dimensional optical elements and waveguides of arbitrary shape in short time.

This technique also provides the basis for the flexible generation of waveguide arrays. While the linear linear propagation in such arrays of evanescently coupled waveguides is well understood, the next consequential step is the investigation of nonlinear effects. Discrete nonlinear self-focusing was first suggested in 1988 and observed in 1998 in etched ridge waveguides on AlGaAs substrates. So far nonlinear results were obtained only in one-dimensional arrays of etched ridge waveguides, by periodic voltage biasing in liquid crystals, in optically induced two-dimensional lattices in compliant media such as in photorefractives and fiber waveguide arrays. Etched arrays are stable but limited to planar configurations while arrays induced in photorefractives do not need manufacturing to modify the structural geometry but are sensitive to real time conditions. Up to now fiber waveguide arrays exhibit strong disorder due to the fabrication process which eliminates homogeneous coupling.

We demonstrated the nonlinear discrete localization in one- and two-dimensional femtosecond laser written waveguide arrays for the first time. The use of fs laser written waveguide arrays exhibits several advantages. All structures induced in the bulk material are permanent and therefore non-sensitive to external distortions. Furthermore all devices are of arbitrary shape and not limited to planar geometries. Up to now only the use of fs written waveguide arrays allows the fabrication of three dimensional nonlinear devices such as nonlinear switches and soliton routers. The investigation of the nonlinear properties of such structures is therefore the base for future nonlinear applications.

For the fabrication of the planar waveguide arrays we used a Ti:Sapphire laser system (RegA/Mira, Coherent Inc.) with a repetition rate of 100 kHz, a pulse duration of about 150 fs and 0.3 μJ pulse energy at a wavelength of 800 nm. The beam was focused into a polished fused-silica sample by a 20 \times microscope objective with a numerical aperture of 0.45. In the focal area multi-photon absorption occurs due to the high energy density, inducing a permanent refractive index change in the material. The focal plane inside the sample was about 150 μm deep. The writing velocity, performed by a positioning system (ALS 130, Aerotech), was as fast as 500 $\mu\text{m/s}$ feasible due to the high repetition rate of the laser system. The resulting index changes were determined by measuring the near-field profile at a wavelength of 800 nm and solving the Helmholtz-Equation. The maximum index change obtained was $\Delta n \approx 1 \cdot 10^{-3}$ with a size of 3 $\mu\text{m} \times 14 \mu\text{m}$. The transmission losses of a single waveguide, measured by a cut-back method, were < 0.4 dB/cm.

Our planar arrays consist of 9 waveguides with a separation of 48 μm and a length of 74 mm. In order to avoid damage of the device when exciting with high power laser pulses, the waveguides are buried 1.5 mm away from the incoupling facet. This reduces the applied fluence at the surface which has a significantly lower damage threshold than the bulk material. For the investigation of the nonlinear propagation properties we used a Ti:Sapphire CPA laser system (Spit-



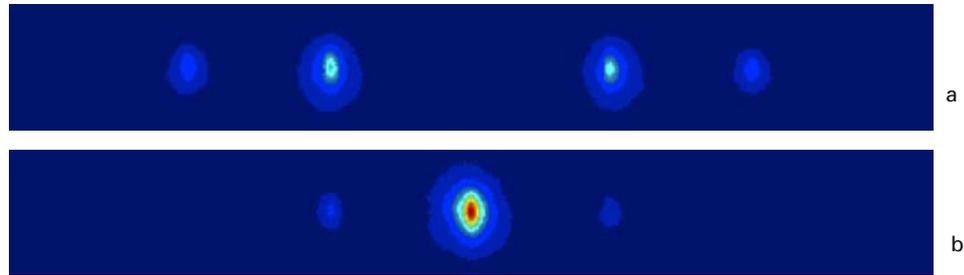


Figure 1: Measured output pattern of the planar waveguide array at 40 kW input peak power (a) and 1000 kW peak power (b).

fire, Spectra-Physics) with a pulse duration of about 100 fs, a repetition rate of 1 kHz and pulse energies of up to 3 μ J at 800 nm. The light was coupled into the center waveguide with a 4 \times microscope objective (NA = 0.10), coupled out by a 10 \times objective (NA = 0.25) and projected onto a CCD-camera. In Figure (1) the measured output pattern of the array is shown at low input peak power (Figure 1a) and at high input peak power (Figure 1b). Whereas in the lower peak power range ($P_{\text{peak}} = 40$ kW) almost all of the guided energy is coupled to the adjacent waveguides due to linear coupling, at a peak power of 1000 kW the output intensity pattern is localized in the center waveguide which has been excited at the entrance. In Figure (2a) the evolution of the experimentally observed output pattern as a function of the input peak power is shown in comparison with a numerical analysis (Figure 2b).

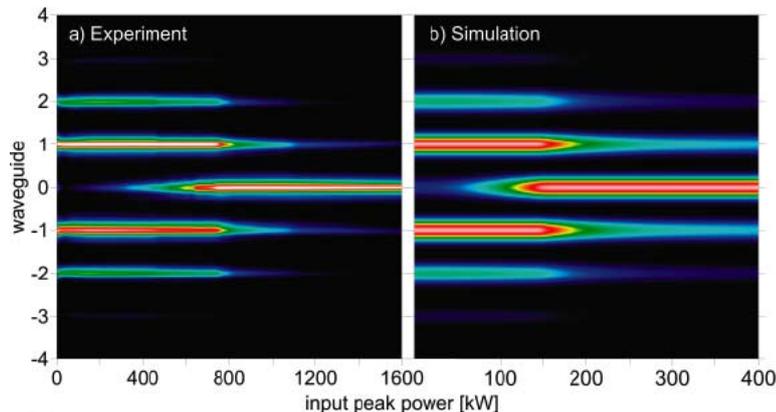


Figure 2: Comparison of the dependence of the output pattern on the input peak power between the experimental data (a) and the numerical analysis (b).

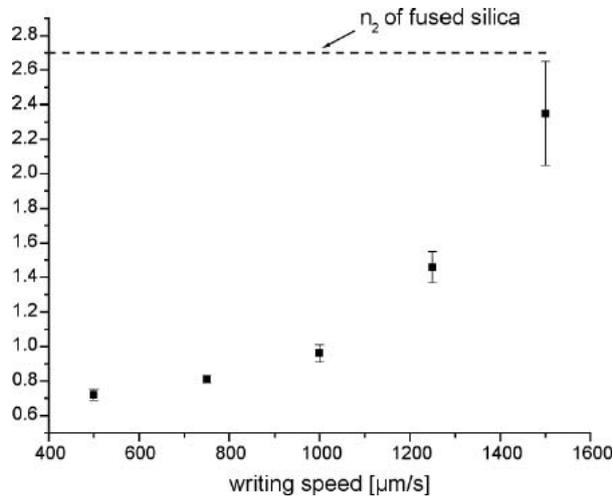


Figure 3:
Dependence of the effective
nonlinear refractive index
on the writing velocity.

While there is excellent qualitative agreement the simulation predicts a lower (approximately a factor of 4) peak power for the localization. This discrepancy is due to the fact that not only the linear but also the nonlinear index of refraction is changed by the writing process. In order to obtain the effective nonlinearity we measured the nonlinear change of the spectra of the femtosecond laser pulses due to self-phase-modulation before and after propagation through the waveguides. By simulating the propagation in the waveguides and comparing the results with the experimental data we obtained the effective nonlinearity. It is a function of the writing velocity as Fig. 3 shows and, therefore, it can be tuned to fit the experimental requirements by choosing appropriate processing parameters. For the planar arrays we used a writing velocity of $500 \mu\text{m/s}$ which reduces the effective nonlinearity in the waveguides to $0.25 n_{2(\text{bulk})}$. To reduce the peak power necessary to observe nonlinear propagation effects one has to use high writing velocities $> 1000 \mu\text{m/s}$ yielding high effective nonlinearities.

With this knowledge we fabricated two-dimensional cubic waveguide arrays using again the Ti:Sapphire laser system (RegA/Mira, Coherent Inc.) with a repetition rate of 100 kHz, a pulse duration of about 150 fs and 0.3 μJ pulse energy at a wavelength of 800 nm. The beam was focused into the polished fused-silica





sample by a 20× microscope objective with a numerical aperture of 0.45. The writing velocity was chosen to be as high as 1250 $\mu\text{m/s}$, again performed by a positioning system (ALS 130, Aerotech). The focal plane inside the sample was about 150 – 350 μm deep. Our arrays consist of 5×5 waveguides with a separation of 40 μm and a length of 74.4 mm. The waveguides were buried 0.5 mm away from the incoupling facet. For the investigation of the nonlinear propagation properties we used the same experimental setup as described above.

The coupling behavior of the outer waveguides in a finite array where the light is coupled back into the inner waveguides corresponds physically to a reflection at the array's boundaries which leads to a significantly different output pattern compared to an infinite array. To study this effect we excited not the center waveguide ($n=m=3$) but the waveguide aside ($m=4, n=3$).

Therefore non-symmetrical effects at the left and the right boundary are obtained. Furthermore the coupling differs in horizontal and vertical direction which is due to the elliptical shape of the waveguides and the corresponding mode profile. In Figure (4a) the output pattern as a result of the interaction between non-isotropic coupling and strong boundary effects at low input peak power ($P_{\text{peak}} = 40 \text{ kW}$) is shown. In contrast the output pattern at 1000 kW Peak Power is shown in Figure (4b). The nonlinear propagation in the waveguides acts as a counterpart to the linear coupling which is almost completely suppressed. Therefore nearly all of the incoupled light is ›trapped‹ in the center waveguide.

It is important to note that for a two-dimensional localization the required peak power for localization is twice the peak power necessary compared to a linear array consisting of the same type of waveguides. Due to the higher writing velocity used compared to the linear array the induced linear refractive index change is lower resulting in stronger coupling between the waveguides. This together with the reduced distance between the waveguides should result in a significantly higher peak power required for localization. However, this is compensated by the high effective nonlinearity, which is only moderately modified due to the writing

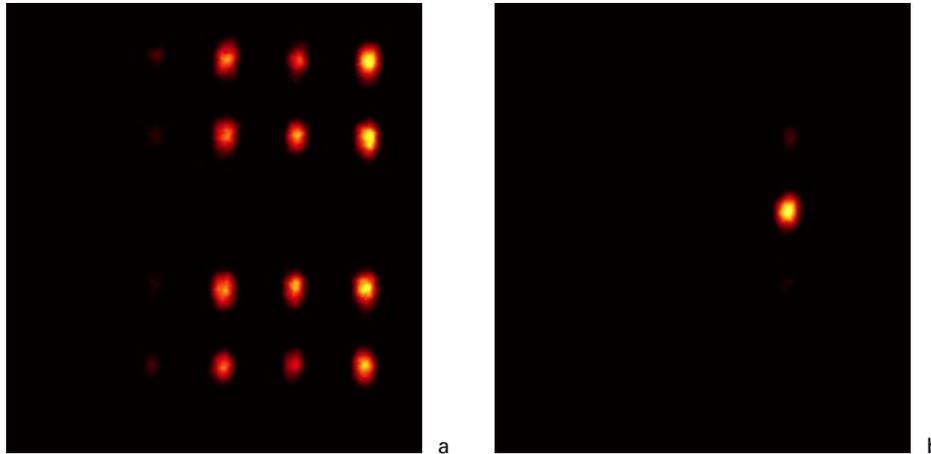


Figure 4: Comparison of the output pattern of a 5x5 cubic waveguide array at 40 kW input peak power (a) and 1000 kW input peak power (b).

process in this case. As a consequence the observed peak powers where localization is observed are comparable in both arrays.

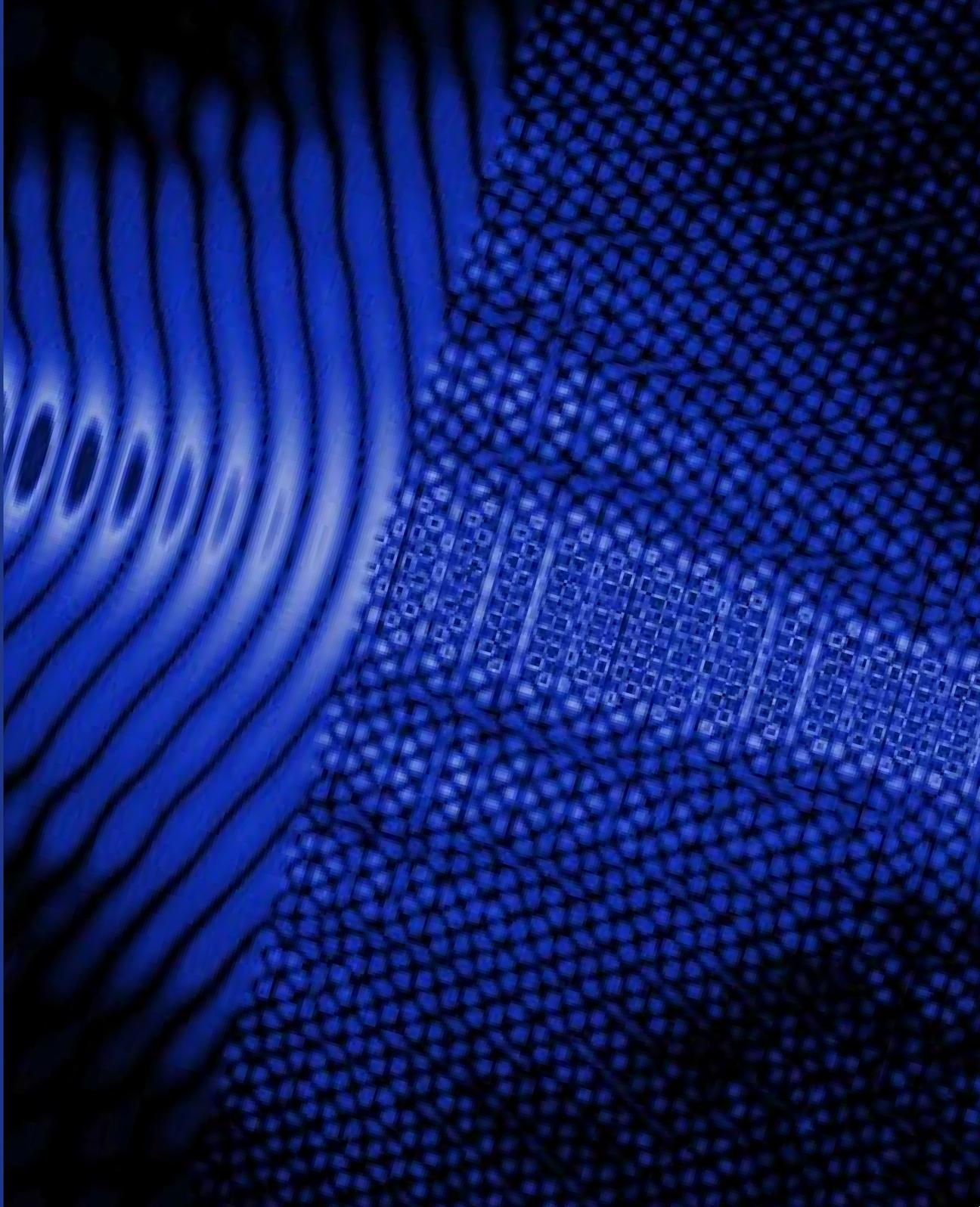
In conclusion we have demonstrated one- and two-dimensional localization in planar and cubic fs laser written waveguide arrays, respectively. Due to the finite size of the cubic array and the sharp edges strong boundary effects were observed. A reduction of the nonlinear refractive index as a function of the writing velocity was observed. This processing parameter dependant change of the nonlinearity is another helpful free parameter for the design of such nonlinear devices as demonstrated. These experiments provide the basis for future research on two-dimensional integrated nonlinear optical devices written by femtosecond laser pulses.

We acknowledge support by the Deutsche Forschungsgemeinschaft (Research Group, »Nonlinear spatial-temporal dynamics in dissipative and discrete optical systems«, FG 532), the Federal Ministry of Education and Research (Innoregio, ZIK) and the Thüringer Kultusministerium.





Achievements & Results



■ Nano Optics

Photonic crystal based optical imaging elements

Thomas Pertsch

Introduction

Photonic crystals are periodic dielectric nanostructures. They affect the propagation of electromagnetic waves in the same way as the periodic potential in a semiconductor crystal affects electron motion; by defining allowed and forbidden electronic energy bands. The absence of allowed propagation modes inside the structures, over a range of wavelengths called a photonic band gap, promises the realisation of optical phenomena like suppression of the spontaneous emission, high-reflecting omni directional mirrors and lossless guiding of light.

The simplest form of a photonic crystal is a one-dimensional periodic structure, such as a multilayer film (a Bragg mirror); electromagnetic wave propagation in such systems was first studied by Lord Rayleigh in 1887, who showed that any such one-dimensional system has a band gap. The possibility of two- and three-dimensionally periodic crystals with corresponding two- and three-dimensional band gaps was not suggested until 100 years after Rayleigh, by Eli Yablonovitch and Sajeev John in 1987. This triggered a fast-paced development which is still ongoing today and has led to optical devices within a few years. Of particular importance are waveguides, resonators and superprisms. However the promising potential of these miniature devices is limited by huge coupling losses to the macroscopic outside world which are caused by the incomparable size of the respective mode fields. A solution to this problem can also be found in Photonic Crystals themselves, although in this regard the existence or size of the band gap is not the important feature but rather that the Photonic Crystal may cause a specific phase change in a light beam leading to a focusing of the beam. Thereby highly efficient coupling to the small mode fields of the Photonic Crystal waveguides should become possible.



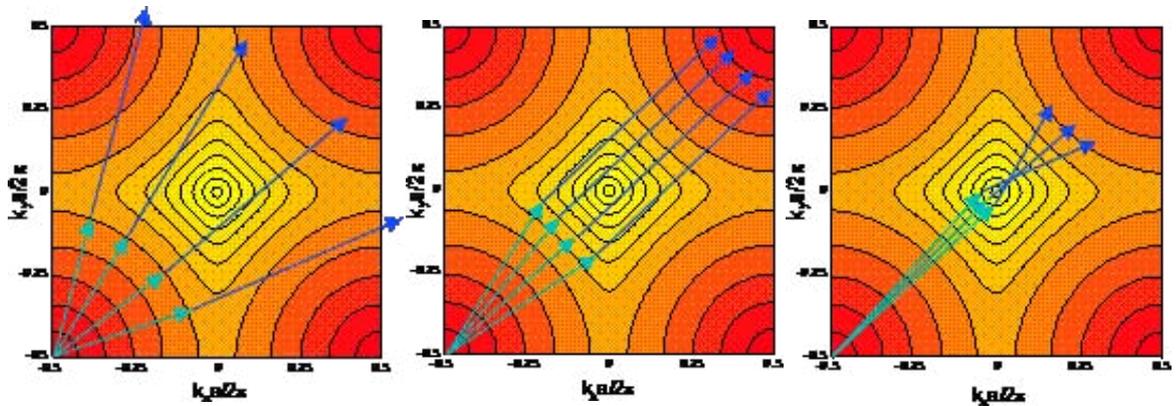


Figure 1: Iso-frequency plots of the first Bloch mode over all possible wavevectors in the Photonic Crystal. Depending on the wavevector and the frequency of the incident light normal diffraction, an almost diffraction less propagation of light or negative diffraction occurs.

Theoretical Discription

The phase change caused by the Photonic Crystal is given by the modes of the periodic media, the so-called Bloch modes, whose properties can be understood in an iso-frequency plot, in which the frequency of the Bloch modes is plotted over all possible wavevectors (k) of the unit cell of the Photonic crystal, the so-called Brillouin zone. If light enters the periodic media, the propagation direction of energy is determined by the normal of the iso-frequency curve at the point given by the frequency and wavevector of the incident light. Depending on the convex or concave curvature of the iso-frequency curve an incident ray of light experiences normal refraction (Fig. 1a), an almost diffractionless propagation (Fig. 1b) or a negative diffraction resulting in a focussing of the light (Fig. 1c). Therefore it is possible to use Photonic Crystals as imaging elements. A prove of principle for imaging a narrow source with a Photonic Crystal is shown in Fig. 2 in terms of a Finite-Difference Time-Domain (FDTD) simulation.

A similar type of focusing is also possible with a material featuring a gradient index distribution. Such a distribution can also be accomplished by a nano-structuring, e.g. if one parameter of the periodic structure, such as the hole diameter is continuously changing. With the help of another FDTD simulation this focusing effect was verified for a structure consisting of air holes in a square lattice with a pitch of 1241 nm and a linear variation of the diameter from 500 nm to 993 nm. In this case a focusing of light with a wavelength of 1.55 μm to a full width half maximum of 1.5 μm was observed in the simulation (Fig. 3).

Figure 2:
Finite-Difference Time-Domain (FDTD) simulation, in which the effect of negative diffraction is apparent. This effect is used here for imaging a Gaussian light source with a Photonic Crystal.

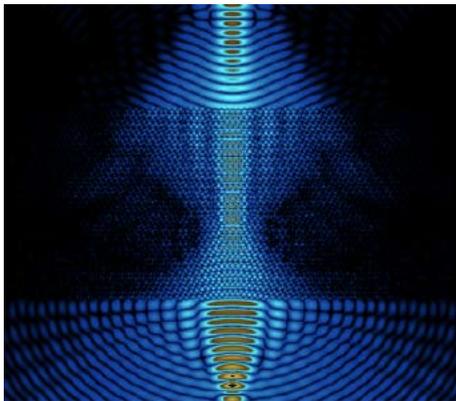
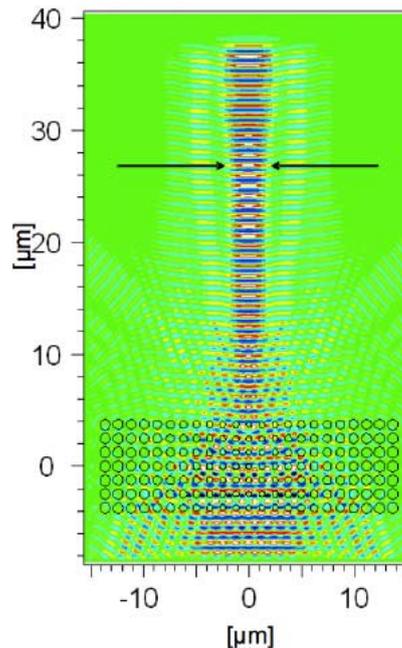


Figure 3:

With a gradient structure focusing can be achieved. In detail, this structure consists of air holes in a square lattice, where from the middle of the structure the hole-diameter is linearly increased. Thereby the focusing of light to a full width half maximum of 1.5 μm is possible.





Realisation

Two dimensional nanostructures were fabricated by electron beam lithography. The vertical confinement of light is accomplished by exploiting the principle of total internal reflection – the photonic crystal is placed between layers of a lower refractive index material. In contrast to reports in the literature, where high index materials such as silicon or gallium arsenide are used for the realization of photonic crystals, the investigations in Jena have been concentrated on silicon nitride, which is also transparent in the visible spectral range. Using silicon nitride, a refractive index of ~ 2 can be found, as opposed to a refractive index >3 of gallium arsenide.

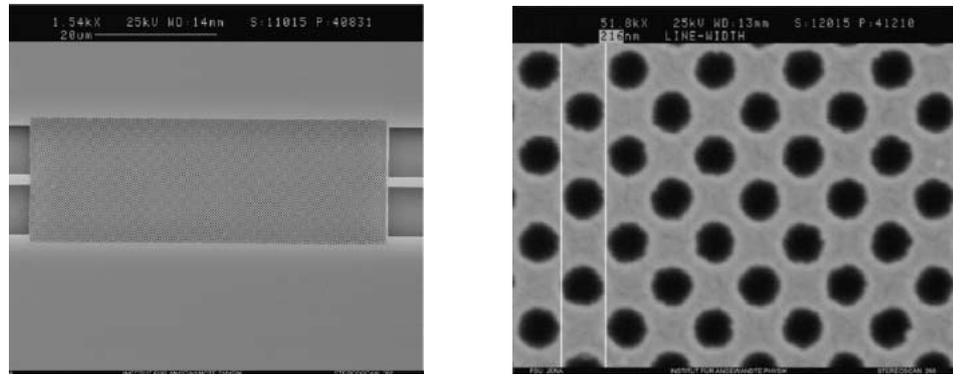


Figure 4: SEM-images of a Photonic Crystal (period: 320 nm, hole diameter 210 nm) allowing the almost diffractionless propagation of light at a wavelength of 810 nm even though no waveguides exist inside the structure.

For the demonstration of the almost diffractionless propagation of light, the negative refraction and the focussing effect of a gradient structure, different samples have been fabricated. Fig. 4 shows a SEM image of a Photonic Crystal, which allows without any defects the guidance of light at a wavelength of 810 nm. With a stray light measurement this property of the Photonic Crystal could be observed directly (Fig. 5). In Fig. 6 a SEM image of a Photonic Crystal is shown featuring negative diffraction at 800 nm as well as a SEM image of a gradient structure exhibiting the desired gradient in the hole diameter and thereby allowing the efficient coupling between a ridge waveguide and a Photonic Crystal waveguide for a wave-

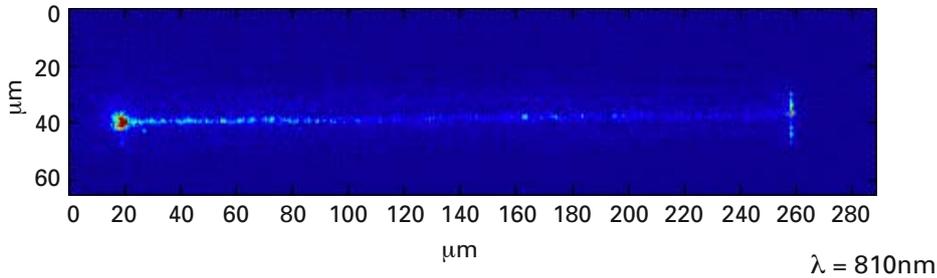


Figure 5: Detected stray light of the Photonic Crystal shown in Fig. 4.

At a wavelength of 810 nm the effect of the almost diffractionless propagation of light over a distance of 250 μm is apparent.

length around 1.55 μm . This waveguide can also be seen in Fig. 6 on the right. Using this technique it should be possible to reduce the huge coupling losses and thereby solve one of the major problems of Photonic Crystal waveguides and thus make them suitable for a wide range of applications.

Support by the Federal Ministry of Education and Research (Unternehmen Region, ZIK) and the Deutsche Forschungsgemeinschaft is acknowledged.

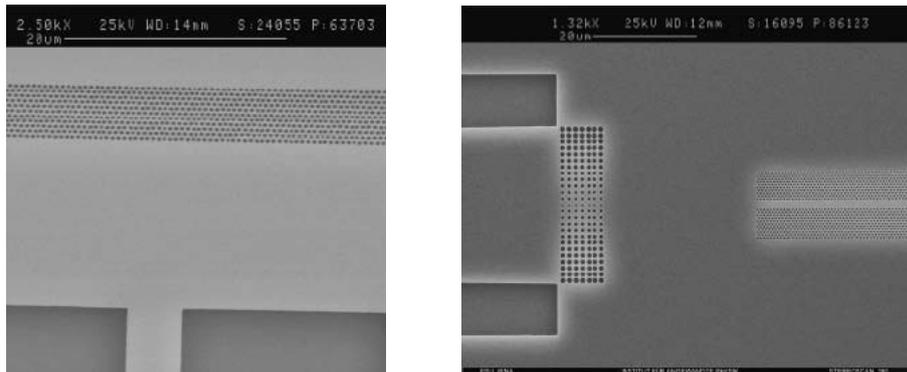
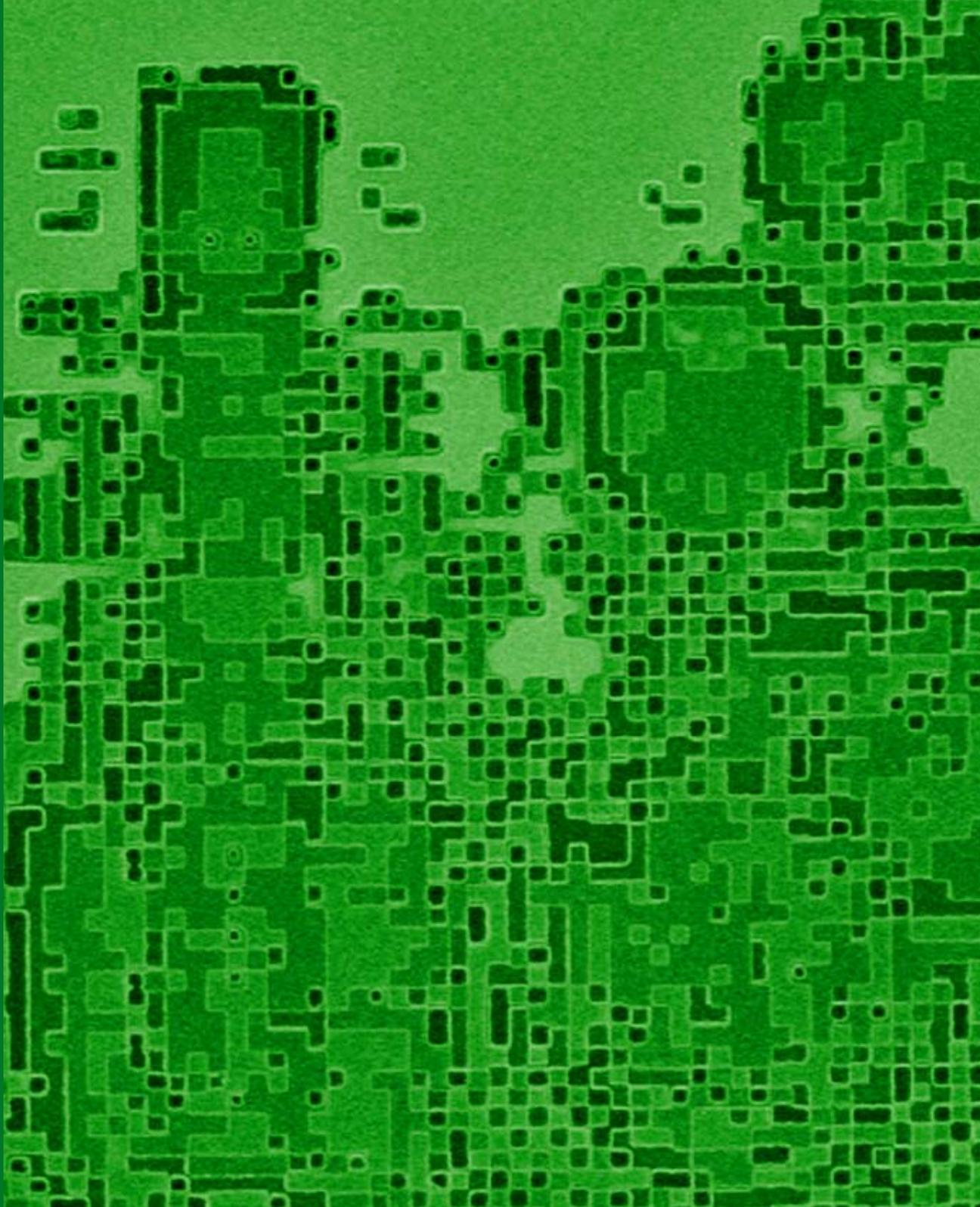


Figure 6: SEM images of structures, which should allow the drastic reduction of coupling losses of Photonic Crystal waveguides. On the left side a periodic structure featuring a negative diffraction at a wavelength of 800 nm is shown. On the right side a gradient structure as well as a Photonic Crystal waveguide is shown, in which light can be coupled using this photonic crystal lens.



Achievements & Results



■ Optical Engineering

Optical Engineering Group: R&D in 2005

Frank Wyrowski

Optics and photonics have become a significant source of technical innovation. Light is utilized in a very flexible way to enable developments in an enormous variety of applications. This major trend is accompanied by an ever increasing demand for advanced optical simulation techniques. In particular wave-optically based methods for modelling optical systems are needed to allow the required manipulation and application of light. The representation of electromagnetic fields as harmonic waves gains momentum and replaces the use of ray bundles more and more in optical engineering. The optical engineering (OE) group at IAP significantly contributes to the development of wave-optical engineering and is well known for this work nationally and internationally. The results in research and development are presented in such a way, that interested partners and colleagues in industry and research may benefit from it very fast. This way the OE group helps to enable innovative developments in optics and photonics. The implementation of the wave-optical engineering techniques in the optics modelling software VirtualLab™ by LightTrans GmbH plays an important role in this context. An ever increasing number of national and international industry and research groups use the R&D of the OE group also by working with VirtualLab™. This is of course also valid in the optics and photonics valley Jena.

The OE research and development in 2005 addressed the following topics:

- Generalization of the harmonic field model to include partial coherent source radiation. This research extends the existing coherence theory to allow the representation of general radiation by superposition of harmonic fields. Meanwhile the results allow the modelling of ultra short pulses, thermal sources, LED's and excimer lasers.





- Further extension and development of the concept of propagation operators for discussing 3d fields in physical optics. Besides the wave-optical field model the operator concept constitutes one of the most essential fundamentals of wave-optical engineering. The OE group at the IAP is leading in this development.
- The operator concept was also used to present an unambiguous definition of scalar and paraxial optics together with a strategy to evaluate the validity of scalar and paraxial models in optical engineering.
- Development of techniques for propagating harmonic fields through optical systems. The local elementary interface approach (LEIA) is still of essential importance for the R&D in this field. Extensions with wave-optical techniques were investigated to develop hybrid techniques and to formulate a smooth transition to beam propagation techniques.
- The design of optical systems to generate electromagnetic radiation with tailored distribution in space was addressed from a new point of view. To this end the approaches for beam splitting, beam shaping and light diffusing were unified and described in a theory for generating tailored harmonic radiation.

These R&D topics will be continued also in 2006. With this work the OE group will further contribute to the formulation of physical optics modelling methods for the generation of tailored electromagnetic radiation. The work on the book with the working title »Physical optics for photon management« (Springer) by Frank Wyrowski, Jari Turunen (Professor Academy of Finland), and Jani Tervo (Assistant Professor University of Joensuu; AvH fellow in 2005 at IAP/LightTrans) will accompany this R&D effort.

The modelling of electromagnetic fields constitutes the key for innovative optics simulation. Thus, some further details on it should be discussed in what follows.

The use of harmonic fields in wave-optical simulation has been established in recent years and replaces ray bundle models in optics simulation more often. Harmonic fields are defined as monochromatic and are characterized by a simple sine dependency in time. This property allows the separation of the time dependency in most optics simulations. As a result harmonic fields are presented as

complex amplitudes. Most popular examples of complex amplitudes are known for plane waves, spherical waves and Gaussian laser beams. Techniques for propagating harmonic fields through optical systems are under investigation in numerous groups worldwide. Methods for efficient propagation of harmonic fields through lens systems, micro and nano structures and through light scattering elements like diffusers are of particular concern in optical engineering.

The consequent use of harmonic fields in optics simulation represents an important progress to allow the exploitation of the innovative potential of optics and photonics. However, harmonic fields do allow the representation of coherent light only. That in particular permits the modelling of single mode lasers. But most real sources emit partial coherent light and the harmonic field model is only useful in a first modelling approximation. That is valid for instance for thermal sources, LED's, excimer and ultra short pulsed lasers. As a consequence innovative optical simulation must address the modelling of partial coherent light. The established way to handle partial coherent light is formulated in coherence theory. Partial coherent fields are presented by a coherence function in this theory. Unfortunately this very elegant mathematical method suffers from a significant drawback in terms of optical engineering. The techniques for propagating harmonic fields can not be directly used to propagate coherence functions. Moreover, established coherence theory sometimes covers the physical nature of partial coherent light a bit for non-experts. In 2005 the OE group has started to model real sources on the base of harmonic field decompositions. This technique has been proven to be very powerful in innovative optics simulation.

The work of the optical engineering group significantly benefits from a close cooperation with the R&D team at LightTrans GmbH. Moreover, the cooperation with the team of Prof. Turunen at the University of Joensuu in Finland is of central concern for the research of the OE group. In addition numerous contacts to national and international research and development teams in industry and universities ensure a continuous exchange of information about the developments in optical simulation and its needs in optics and photonics.



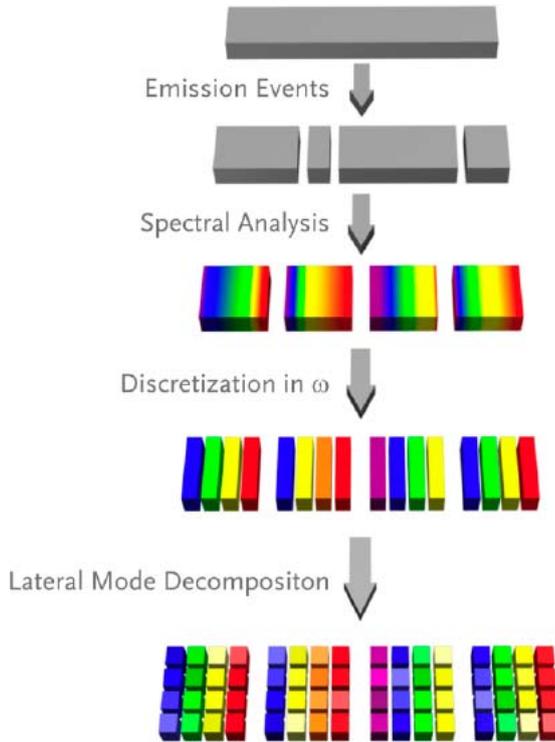
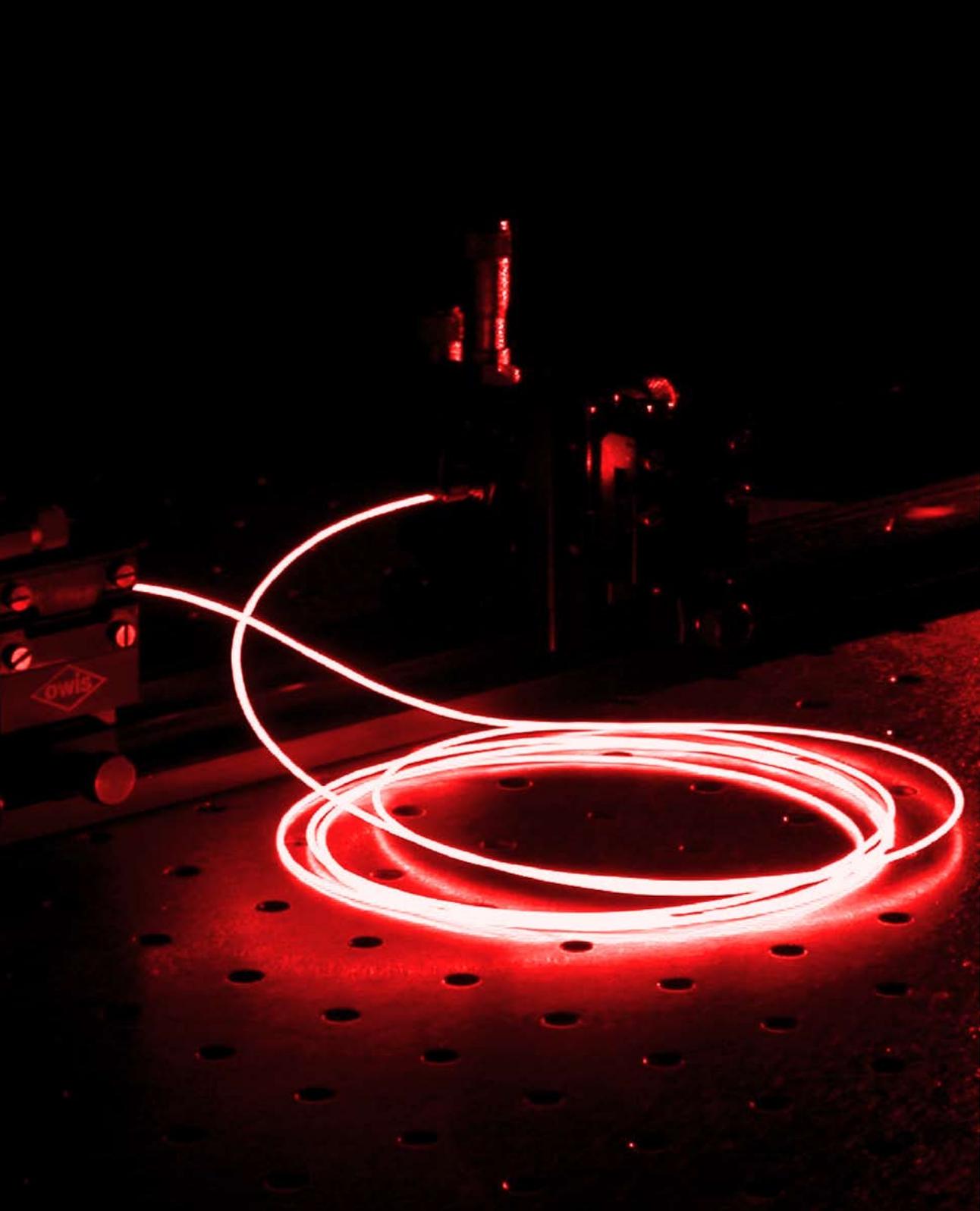


Illustration of the idea to decompose a real field into an ensemble of harmonic fields. The original field is described in the first row by the gray rectangular. The temporal field dependency includes statistical variations due to the emission characteristics of the real source. Dependent on the source the field may be separated in time intervals which are related to characteristic emission events. That is illustrated in the second row. We may also say that the fields in the second row form an ensemble of fields which represent the original field. The ensemble includes the statistics of the source. By a harmonic analysis of each ensemble member the representation in the Fourier domain is obtained. In practical engineering it is consequent to sample these functions in frequency and harmonic field per ensemble result.

Dependent on the source a further decomposition of each harmonic field into lateral modes may be of advantage, to discuss the statistics of the ensemble. That is illustrated in the last row. Dependent on physical assumptions on the emission events in the real source it is possible to specify the harmonic field decomposition and by that to model partial coherent light as it is radiated by real sources.



Achievements & Results



■ Fiber & Waveguide Lasers

Fiber Laser – Microstructures open new possibilities

Jens Limpert

Introduction

Over the past few years rare-earth-doped fiber lasers and amplifiers have proved to be a power-scalable solid-state laser concept. Continuous-wave output powers in the kilowatt range with excellent beam quality have been demonstrated. These results are possible because of several inherent properties of active fibers. Their main performance advantages arise from the fact that they can simultaneously guide pump and laser radiation through waveguide structures. The refractive-index profile of the doped core determines the mode quality of the laser output, which is therefore power independent. Furthermore, the large ratio of surface to active volume ensures excellent heat dissipation, which makes a fiber laser basically immune to thermo-optic problems.

The guidance of pump radiation guarantees a large product of pump intensity and interaction length, which is the reason for the high single-pass gain of rare-earth-doped fiber. However, non linear optical effects arise in conventional single-mode fibers due to high intensities created by the tight confinement of the laser radiation in typical core diameters of $\sim 10 \mu\text{m}$ together with the extended length of material over which the laser interacts, which can be up to several tens of meters.

These nonlinear effects, in particular inelastic Raman scattering and self-phase modulation resulting from the intensity dependent refractive index, are in general the main performance limitations of fiber lasers and amplifiers. The nonlinearity of a fiber scales with the fiber length and is inversely proportional to the mode-field area. Therefore, the employment of short, large-mode-area fibers allows for significant power scaling.

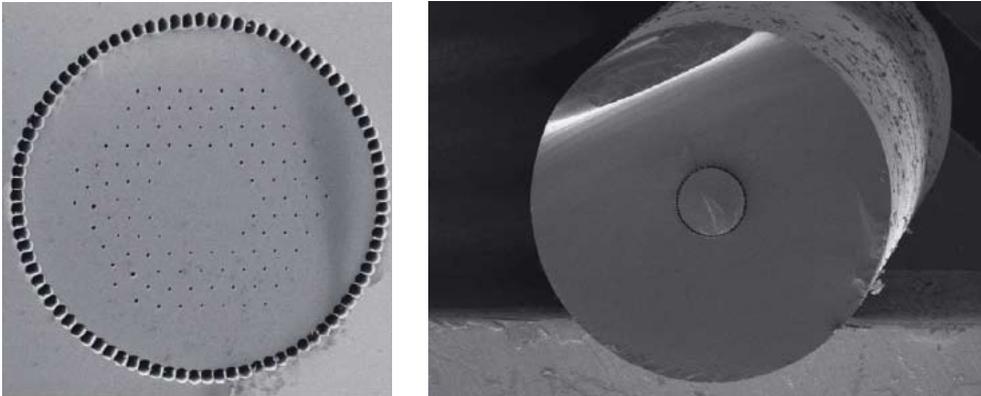


Figure 1: Microscope image of a rod-type photonic crystal fiber (right) and close-up view of the inner cladding and core regions (left).

Rod-type photonic crystal fibers – Low-nonlinearity fibers

Our work focused on novel fiber designs to overcome the conventional limitations of fiber lasers and amplifiers. By microstructuring a fiber, new functionality can be added. As a result we designed a large-mode-area photonic crystal fiber with the outer dimensions of a rod laser and the performance of a fiber laser. The basic idea of this fiber design is to have the outer dimensions of a rod laser; meaning a diameter in the range of a few millimeters and a length of just a few tens of centimeters, but to include two important waveguide structures; one for pump radiation and one for laser radiation. Finally, such a fiber has a radically reduced nonlinearity and therefore allows for significant power and energy scaling.

One can achieve the reduction of fiber length by reducing the ratio of pump core area to active core area, which increases the pump light absorption of the double-clad fiber. The inner cladding of this fiber is surrounded by an air – cladding region, as shown in Fig. 1. The inner cladding has a diameter of $\sim 180 \mu\text{m}$



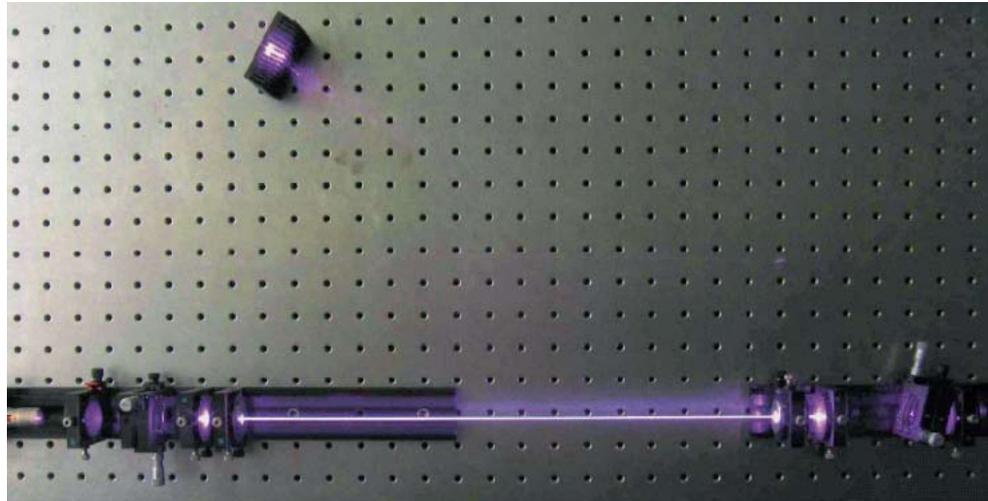


Figure 2: Experimental setup of a short-length high-power fiber laser.

with a numerical aperture as high as 0.6. The ytterbium-doped core has a diameter of $\sim 60 \mu\text{m}$, leading to pump light absorption by this structure of $\sim 30 \text{ dB/m}$ at 976 nm. It is important to note that, because of the unchanged product of pump intensity and fiber length compared with other double-clad fiber designs, the high single-pass gain of the fiber is maintained even over an extremely short fiber length. Therefore, this rod-type fiber also features a low lasing threshold and high efficiency as is the case for conventional fiber dimensions.

Usually, the extraction of high-power levels from short fiber lengths is limited by thermo-optic problems. A detailed analysis of the thermo-optic behavior of high-power fiber lasers (including photonic crystal fibers) has revealed that power scaling is restricted by damage to the polymer coating, which occurs at fiber surface temperatures between 100 and 200 °C. These temperatures are easily reached if power levels in the 100 W/m range are extracted. In a conventional double-clad fiber the coating has an optical function.

The coating has to have a lower refractive index than fused silica and therefore forms the waveguide for pump radiation. But in a microstructured air-clad fiber, it just serves to protect the fiber from mechanical damage and chemical attack. The most straightforward way of avoiding coating damage is to remove the coating. This can be done if the fiber itself has enough mechanical stability, i.e., if the fiber is thick enough.

The fiber shown in Fig. 1 has an outer cladding diameter amounting to 2 mm and possesses no coating. In addition, the larger outer diameter improves the heat dissipation capabilities of this fiber and also reduces the propagation loss of weakly guided radiation that is due to the increased rigidity. A fiber laser in its simplest form is built by use of just a 50-cm length of the 60 μm ytterbium-doped core rod-type fiber discussed here. Compared to conventional step-index fibers the nonlinearity is reduced by a factor of 2000. The laser is pumped from two sides, and the fiber ends are perpendicularly polished.

The cavity is formed by a high reflecting mirror on one side and $\sim 4\%$ Fresnel reflections on the other side. Figure 2 shows a photograph of the experimental setup. We obtained 260 W of single-transverse-mode laser output power from this fiber sample with a slope efficiency of 75 %. This corresponds to an extracted power greater than 500 W/m, which to our knowledge is the highest value ever reported for fiber lasers.

Single-polarization photonic crystal fiber

Due to the up-scaling of the nonlinear limits, which are greatly reduced due to the larger single-mode cores and shorter absorption of air-clad large mode area photonic crystal fibers, as described above, a dramatic scaling of the output of fiber laser systems is achieved. Usually, in these high power experiments a degradation of the degree of polarization is observed.





To overcome this problem and especially to simplify the laser setup in terms of polarization control, there is considerable interest in combining large mode area microstructured fibers and polarization maintaining elements.

Our investigations focused on polarization maintaining fibers based on stress-induced birefringence in photonic crystal fibers. We found that the microstructure itself does not limit the application of stress applying parts (SAPs) to achieve birefringence but that a fiber with low nonlinearity is difficult to achieve. Therefore, we developed a novel design of photonic crystal fiber that includes stress-applying elements as part of the photonic cladding. Beside the stress-induced birefringence, the light is confined by both parts of the photonic cladding: the air holes and the index matched regular array of SAPs. Such a fiber is shown in Fig. 3. We found that the birefringence is enough to split two polarization states of the weakly guided fundamental mode in such a way that the effective index of one polarization is below the cladding index, thus, resulting in a single polarization, large mode area fiber. The mode field area of $\sim 700 \mu\text{m}^2$ is larger than that of any step-index single mode fibers.

The fiber was tested in low power operation and showed a very similar performance to a comparable non-polarization maintaining fiber, but of course with almost perfectly polarized output. In a new experiment, up to 147 W of output power could be extracted, as shown in Fig. 4, which was again limited by the



Figure 3: SEM image of the Yb-doped air-clad photonic crystal fiber with six index-matched stress applying parts.

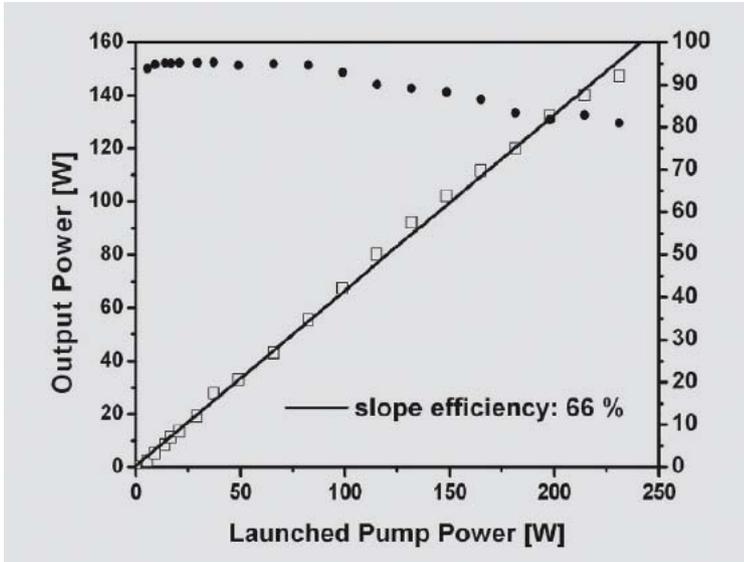


Figure 4:
Output characteristics
of a free running laser
using the single polarization
Yb-doped LMA fiber.

available pump power. The slope efficiency with respect to the launched pump power was 66 %.

The degree of polarization is above 95 % (>16 dB extinction ratio) for output powers up to 50 W. At the highest power level, the degree of polarization is still 82 %. Besides the potential of such a new fiber design of high power lasers with polarized output, the fiber can be used as an amplifier. The low nonlinearity in particular predestines this fiber to be a polarization maintaining gain medium in ultra-short pulse amplifier systems. The polarization maintaining properties have also been experimentally verified and showed an extinction ratio of the amplifier output of more than 24 dB (1:250).

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■ Publications

Journals

M. Augustin, R. Iliew, C. Etrich, D. Schelle, H.-J. Fuchs, U. Peschel, S. Nolte, E.-B. Kley, F. Lederer, A. Tünnermann

Self-guiding of infrared and visible light in photonic crystal slabs

Appl. Phys. B 81, 313 – 319 (2005)

T. Clausnitzer, E.-B. Kley, A. Tünnermann, A. Bunkowski, O. Burmeister, K. Danzmann, R. Schnabel, S. Gliech, A. Duparré

Ultra low-loss low-efficiency diffraction gratings

Optics Express Vol. 13 (12), p. 4370-4378 (Jun. 2005)

<http://www.opticsinfobase.org/abstract.cfm?URI=oe-13-12-4370>

T. Clausnitzer, A. V. Tishchenko, E.-B. Kley, H.-J. Fuchs, D. Schelle, O. Parriaux, U. Kroll

Narrowband, polarization-independent free-space wave notch filter

JOSA A, Vol. 22 No. 12, p. 2799-2803 (Dec. 2005)

A. Duparré, M. Flemming, G. Notni, A. Tünnermann

Nanorauheit statt Lotusstruktur:

Chancen für ultrahydrophobe optische Oberflächen

Photonik 2, 62 (2005)

J. Duparré, P. Dannberg, P. Schreiber, A. Bräuer, A. Tünnermann

Thin compound-eye camera

Appl. Opt. 44, 2949 (2005)

*J. Duparré, P. Schreiber, A. E. Matthes, E. Pshenay-Severin, A. Bräuer,
A. Tünnermann, R. Völkel, M. Eisner, T. Scharf*

Microoptical telescope compound eye

Optics Express 13, 889 (2005)

U. Fuchs, U. D. Zeitner, A. Tünnermann

Ultra-short pulse propagation in complex optical systems

Optics Express 13,3852 (2005)

*R. Iliw, C. Etrich, U. Peschel, F. Lederer, M. Augustin, H.-J. Fuchs,
D. Schelle, E.-B. Kley, S. Nolte, A. Tünnermann*

Diffractionless propagation of light in a low-index photonic-crystal film

Appl. Phys. Lett. 85 (24), p. 5854-5856 (Dez. 2004)

R. Iwanow, R. Schiek, G. Stegeman, T. Pertsch, F. Lederer, Y. Min, W. Sohler

Arrays of weakly coupled, periodically poled lithium niobate waveguides:
beam propagation and discrete spatial quadratic solitons

Opto-Electron. Rev. 13, 113 (2005)

R. Iwanow, G. Stegeman, R. Schiek, T. Pertsch, F. Lederer, Y. Min, W. Sohler

Highly localized discrete quadratic solitons

Opt. Lett. 30, 1033-1035 (2005)

H. Lajunen, J. Turunen, P. Vahimaa, J. Tervo, and F. Wyrowski

Spectrally partially coherent pulse trains in dispersive media

Opt. Commun., 255, 12-22 (2005)





J. Limpert, C. Aguergaray, S. Montant, I. Manek-Hönniger, S. Petit, D. Descamps, E. Cormier, F. Salin

Ultra-broad bandwidth parametric amplification at degeneracy

Opt. Express 13, 7386-7392 (2005)

J. Limpert, N. Deguil-Robin, I. Manek-Hönniger, F. Salin, F. Röser, A. Liem, T. Schreiber, S. Nolte, H. Zellmer, A. Tünnermann, J. Broeng, A. Petersson, C. Jakobsen

High-power rod-type photonic crystal fiber laser

Opt. Express 13, 1055 – 1058 (2005)

J. Limpert, N. Deguil-Robin, I. Manek-Hönniger, F. Salin, T. Schreiber, A. Liem, F. Röser, H. Zellmer, A. Tünnermann, A. Courjaud, C. Hönniger, E. Mottay

High-power picosecond fiber amplifier based on nonlinear spectral compression

Opt. Lett. 30, 714-716 (2005)

J. Limpert, N. Deguil-Robin, S. Petit, I. Manek-Hönniger, F. Salin, P. Rigail, C. Hönniger and E. Mottay

High power Q-switched Yb-doped photonic crystal fiber laser

producing sub-10 ns pulses

Applied Phys. B 81, 1, 19 (2005)

A. H. Nejadmalayeri, P. R. Herman, J. Burghoff, M. Will, S. Nolte, A. Tünnermann

Inscription of optical waveguides in crystalline silicon by mid-infrared

femtosecond laser pulses

Opt. Lett. 30, 964 – 966 (2005)

*C. K. Nielsen, B. Ortaç, T. Schreiber, J. Limpert, R. Hohmuth, W. Richter,
A. Tünnermann*

Self-starting self-similar all-polarization maintaining Yb-doped fiber laser
Opt. Express 13, 9346-9351 (2005)

S. Nolte, D. Blömer, J. Burghoff, A. Szameit, M. Will, A. Tünnermann

Ultrafast laser processing – novel options for photonic device production
Glass Sci. Technol. 78 Suppl. C, 141 – 147 (2005)

*T. Pertsch, R. Iwanow, R. Schiek, G. Stegeman, U. Peschel, F. Lederer,
Y. H. Min, W. Sohler*

Spatial ultrafast switching and frequency conversion
in lithium niobate waveguide arrays
Opt. Lett. 30, 177-179 (2005)

*F. Röser, J. Rothhard, B. Ortac, A. Liem, O. Schmidt, T. Schreiber,
J. Limpert, A. Tünnermann*

131 W 220 fs fiber laser system
Opt. Lett. 30, 2754-2756 (2005)

R. Schiek, R. Iwanow, G. Stegeman, T. Pertsch, F. Lederer, Y. Min, W. Sohler

Low-power, multiport, ultrafast, parametric switching
in cascaded waveguide coupler
Appl. Phys. Lett. 87, 011109 (2005)





P. Senthilkumaran, F. Wyrowski, H. Schimmel

Vortex Stagnation problem in iterative Fourier transform algorithms

Optics and Lasers in Engineering, VOL 43, Pages 43-56, 2005

T. Schreiber, H. Schultz, O. Schmidt, F. Röser, J. Limpert, A. Tünnermann

Stress-induced birefringence in large-mode-area micro-structured optical fibers

Opt. Express 13, 3637-3646 (2005)

T. Schreiber, F. Röser, O. Schmidt, J. Limpert, R. Iliew, F. Lederer, A. Petersson,

C. Jacobsen, K. P. Hansen, J. Broeng, A. Tünnermann

Stress-induced single-polarization single-transverse mode photonic crystal fiber with low nonlinearity

Opt. Express 13, 7621-7630 (2005)

A. Tünnermann

High-power fiber lasers – present and future

Laser-Technik-Journal, June no. 2, 54 (2005)

A. Tünnermann, T. Schreiber, F. Röser, A. Liem, S. Höfer, H. Zellmer,

S. Nolte, J. Limpert

The renaissance and bright future of fibre lasers

J. Phys. B 38, S681 – S693 (2005)

*A. Tünnermann, S. Höfer, A. Liem, J. Limpert, M. Reich, F. Röser, T. Schreiber,
H. Zellmer, T. Peschel, V. Guyenot*

Power Scaling of High-Power Fiber Lasers and Amplifiers

Laser Physics, Vol. 15, No. 1, 2005, pp. 107–117

*S. Wise, V. Quetschke, A.J. Deshpande, G. Mueller, D.H. Reitze, D.B. Tanner,
B. F. Whiting, Y. Chen, A. Tünnermann, E.-B. Kley, T. Clausnitzer*

Phase effects in the diffraction of light: beyond the grating equation

Phys. Rev.. Lett. Vol. 95 (1), p. 013901-1 – 013901-4 (Jul. 2005)

F. Wyrowski, J. Turunen

Local interface techniques in wave-optical engineering

T.P. Jansson, editor, Tribute to Emil Wolf: science and engineering legacy of physical optics,
chapter 18, pages 379–400 (SPIE Press, Bellingham, 2005)

H. Zellmer, S. Nolte, A. Tünnermann

Faserlaser

Physik Journal 6, 29 – 34 (2005)





Invited talks and tutorials

E.-B. Kley

Lithography for Micro- and Nanooptics

AOMATT 2005, 2-5 November 2005 Xian, China

E.-B. Kley

Micro- and Nanostructured Optics

7-th International Conference-School »ADVANCED MATERIALS AND TECHNOLOGIES«

27-31 October 2005, Palanga, Lithuania

E.-B. Kley, A. Tünnermann

Micro- and nano-optics: design, manufacturing and application

4th Sino-German Symposium on Micro and Nano Technologies, Braunschweig (2005)

A. Liem, M. Reich, F. Röser, T. Schreiber, S. Nolte, H. Zellmer,

J. Limpert, A. Tünnermann

Ultrafast Fiber Lasers and Amplifiers - Novel Light Sources for High Precision

Micro Machining

Proc. ASSP, WE1 (2005)

J. Limpert

Hochleistungs-Faserlasersysteme basierend auf mikrostrukturierten Fasern

Bayerisches Laserseminar 2005 Faser, Faser, Scheibe, Slab: Status der neuen Technologien heute,

Erlangen April 2005

J. Limpert, F. Röser, T. Schreiber, A. Tünnermann

High Performance Ultrafast Fiber Laser Systems

LEOS Annual Meeting 2005, Sydney, Australia, paper WV1

J. Limpert, T. Schreiber, F. Röser, A. Liem, A. Tünnermann, F. Salin
Microstructure fibers for high power generation and handling
OFC/NFOEC 2005 Workshop on Photonic Crystal Fibers, Anaheim, CA, USA, paper OSuA5

C. K. Nielsen, B. Ortaç, T. Schreiber, J. Limpert, R. Hohmuth, W. Richter, A. Tünnermann
Self-starting self-similar all-polarization maintaining Yb-doped fiber laser
Opt. Express 13, 9346-9351 (2005)

S. Nolte, D. Blömer, J. Burghoff, A. Szameit, M. Will, A. Tünnermann
Ultrafast laser processing – novel options for photonic device production
Symposium »Novel Optical Technologies«,
79th Annual Meeting of the Deutsche Glastechnische Gesellschaft (DGG), Würzburg (2005)

U. Peschel, T. Pertsch, F. Lederer
Fundamentals and applications of discrete and lattice solitons
CLEO/Europe-EQEC Conference, paper CD6-5-THU (2005)

T. Schreiber, T. V. Andersen, D. Schimpf, J. Limpert, A. Tünnermann
Novel details of supercontinuum generation in photonic crystal fibers
Opt. Express 13, 9556-9569 (2005)

J. Tervo, F. Wyrowski
On Physical Optics Modelling For Optical Engineering
EOS Diffractive Optics Topical Meeting 2005, Warsaw

A. Tünnerman
Advanced miro and nano-optics
New frontiers in Optical Technologies, Tampere, Finland 2005





A. Tünnermann

Faserlaser

Kongress: Neuste Entwicklungen in der Lasertechnik, Volkswagen AG, Wolfsburg (2005)

A. Tünnermann

High power fiber lasers

New frontiers in Optical Technologies, Tampere, Finland 2005

A. Tünnermann

Large mode area fibers for high power laser operation based on solid- and air-microstructured cores High-power fibre lasers and amplifiers

Photonics West, SPIE vol. 5709 San Jose (2005)

A. Tünnermann

Optische Technologie: Historie und Bedeutung in Deutschland

»Licht im Norden«, Neumünster 2005

A. Tünnermann

Photonische Nanostrukturen in Natur und Technik

InnovationsForum Photonik, Goslar (2005)

A. Tünnermann

Status and perspectives of fiber lasers and amplifiers, (Plenary)

Proc. CLEO-Europe, PL1-1-MON (2005)

A. Tünnermann

Status and perspectives of fiber lasers and amplifiers

Conference on Lasers and Electro-Optics (CLEO-Europe), Munich (2005) – plenary

A. Tünnermann

Status and perspectives of fiber lasers and amplifiers

Sino-German Workshop: Advances in Diodes and Diode Pumped Lasers, Beijing (2005)

A. Tünnermann, S. Höfer, J. Limpert, A. Liem, T. Schreiber, M. Reich, H. Zellmer
Large mode area fibers for high power laser operation based
on solid- and air-microstructured cores
Photonics West, SPIE vol. 5709 San Jose (2005)

A. Tünnermann, J. Limpert
High power ultrashort pulse fiber amplifiers
OptoNet-Workshop: Neue Laserstrahlquellen, Jena (2005)

*A. Tünnermann, A. Liem, M. Reich, F. Röser, T. Schreiber, S. Nolte, H. Zellmer,
J. Limpert*
Ultrafast Fiber Lasers and Amplifiers:
Novel Light Sources for High Precision Micro Machining
Advanced Solid State Photonics (ASSP), Wien, Österreich (2005)

F. Wyrowski
Innovation Through Photonics by Harnessing Light
Plenary Presentation:, Opto Ireland 2005

F. Wyrowski, S. Veetil Poyyil, H. Schimmel
A simulation tool to model pulse propagation through linear systems
International Conference on Optics & Optoelectronics ICOL 2005, India

*F. Wyrowski, Friedrich-Schiller-Univ. Jena (Germany);
H. Schimmel, LightTrans GmbH (Germany)*
In the tradition of Ernst Abbe:
innovation through wave optics in optical engineering
SPIE OPTICAL DESIGN AND ENGINEERING II, Jena





Conference Contributions – Invited Talks

M. Augustin, H.-J. Fuchs, E.-B. Kley, S. Nolte, A. Tünnermann, R. Iliew, C. Etrich, U. Peschel, F. Lederer

Investigation of self-guided light in a low-index photonic-crystal
Conference on Lasers and Electro-Optics (CLEO) 2005

M. Augustin, H.-J. Fuchs, E.-B. Kley, S. Nolte, A. Tünnermann, R. Iliew, C. Etrich, U. Peschel, F. Lederer

Selfguiding of Visible Light in Photonic Crystal Slabs
European Conference on Lasers and Electro-Optics (CLEO/Europe) 2005

M. Augustin, R. Iliew, C. Etrich, H.-J. Fuchs, D. Schelle, U. Peschel, E.-B. Kley, S. Nolte, F. Lederer, A. Tünnermann

Self-Guiding of Light in a Low-Index Photonic-Crystal Film
CLEO, Baltimore, USA (2005)

D. Blömer, A. Szameit, J. Burghoff, T. Schreiber, S. Nolte, A. Tünnermann
Nonlinear Effects in fs-laser written Waveguides in Fused Silica
CLEO/Europe, München (2005)

G. Bonati, H. Voelckel, T. Gabler, U. Krause, A. Tünnermann, J. Limpert, A. Liem, T. Schreiber, S. Nolte, H. Zellmer

1.53 kW from a single Yb-doped photonic crystal fiber laser
Photonics West, San Jose, Late Breaking Developments, Session 5709-2a (2005)

J. Burghoff, M. Will, S. Nolte, A. Tünnermann, A.H. Nejadmalayeri, P.R. Herman
Photonics in silicon using mir-IR femtosecond pulses

Photonics West/LASE, San Jose, USA (2005)

*T. Clausnitzer, T. Kaempfe, E.-B. Kley, A. Tünnermann, U. Peschel,
A.V. Tishchenko, O. Parriaux*

High-efficiency transmission gratings for unpolarized illumination:
an intelligible analysis of the diffraction process

Optical Design and Engineering II, Proc. SPIE Vol. 5962, L. Mazuray, R. Wartmann,
eds., p. 367-374 (Sep. 2005)

*T. Clausnitzer, E.-B. Kley, A. Tünnermann, A. Bunkowski, O. Burmeister,
K. Danzmann, R. Schnabel, A. Duparré, S. Gliech*

Low-loss gratings for next-generation gravitational wave detectors

Advances in Thin-Film Coatings for Optical Applications II, Proc. SPIE Vol. 5870, M. L. Fulton, J. D.
Kruschwitz, eds., p. 153-160 (Sep. 2005)

*T. Clausnitzer, T. Schreiber, F. Roeser, J. Limpert, E.-B. Kley, H.-J. Fuchs,
A. Tünnermann*

Highly efficient dielectric gratings for high power ultrafast fiber laser systems

in Commercial and Biomedical Applications of Ultrafast Lasers VII, J. Neev, C. B. Schaffer,
A. Ostendorf, S. Nolte eds., Proc. SPIE Vol. 5714, p. 290-301 (Mar. 2005)

*N. Deguil-Robin, J. Limpert, I. Manek-Hönninger, F. Salin, A. Liem,
T. Schreiber, F. Röser, S. Nolte, H. Zellmer, A. Tünnermann, J. Broeng,
A. Petersson, C. Jakobson*

Rod-Type Fiber Laser

Advanced Solid State Photonics (ASSP), Wien, Österreich (2005)

H. Elfstrom, T. Vallius, M. Kuittinen, T. Clausnitzer, E.-B. Kley

High efficiency in beam splitters fabricated over thin film stacks

Holography, Diffractive Optics, and Applications II, Proc. SPIE Vol. 5636, Y. Sheng,
D. Hsu, Ch. Yu, B. Lee, eds., p. 368-373 (Feb. 2005)





M. Gerken, R. Boschert, R. Bornemann, U. Lemmer, D. Schelle, M. Augustin, E.-B. Kley, A. Tünnermann

Transmission measurements for the optical characterization of 2D-photonic crystals

Optical Fabrication, Testing, and Metrology II, Proc. SPIE Vol. 5965, A. Duparré, R. Geyl, L. Wang, eds., p. 143-149 (in print)

F. Garwe, U. Huebner, T. Clausnitzer, E.-B. Kley, U. Bauerschaefer

Elongated gold nanostructures in silica for metamaterials:

Technology and optical properties

Metamaterials, Proc. SPIE Vol. 5955, T. Szoplik, E. Özbay, C. M. Soukoulis, N. I. Zheludev, eds., p. 185-192 (Sep. 2005)

H. Hartung, T. Clausnitzer, E.-B. Kley, A. Tünnermann

Near field holography with a two-dimensional phase mask for fabrication of two-dimensional structures in a single exposure step

Optical Fabrication, Testing and Metrology, Proc. SPIE 5965, A. Duparré, R. Geyl, L. Wang, eds., p. 40-49 (in print)

R. Iliew, C. Etrich, U. Peschel, F. Lederer, M. Augustin, H.-J. Fuchs, D. Schelle, E.-B. Kley, S. Nolte, A. Tünnermann

Highly Dispersive Photonic-Crystal Waveguides

CLEO, Baltimore, USA (2005)

R. Iliew, C. Etrich, U. Peschel, F. Lederer, M. Augustin, H.-J. Fuchs, E.-B. Kley, S. Nolte, A. Tünnermann

Diffractionless Propagation of TE and TM polarized Light in Photonic Crystal Slabs operating in the Visible Spectral Range

European Conference on Integrated Optics (ECIO) 2005

T. Kaempfe, E.-B. Kley, A. Tünnermann

Design and fabrication of refractive and diffractive micro optical elements used in holographic recording setups

Optical Fabrication, Testing, and Metrology II, Proc. SPIE Vol. 5965, A. Duparré, R. Geyl, L. Wang, eds., p. 17–28 (in print)

T. Kaempfe, E.-B. Kley, A. Tünnermann

Dielectric pinholes for laser beam filtering

Micromachining Technology for Microoptics and Nanooptics III, Proc. SPIE Vol. 5720, E.-G. Johnson, G.-P. Nordin, T.-J. Suleski, eds., p.156–164 (Feb. 2005)

T. Kaempfe, E.-B. Kley, A. Tünnermann

Hybrid approach to the design of refractive beam shaping elements

Laser Beam Shaping VI, Proc. SPIE Vol. 5876, F.-M. Dickey, D.-L. Shealy, eds., p.163–175 (Aug. 2005)

T. Kaempfe, E.-B. Kley, A. Tünnermann

Laser beam filtering by refractive or diffractive microstructures

Current Developments in Lens Design and Optical Engineering, Proc. SPIE Vol. 5873, P.-Z. Mouroulis, W.-J. Smith, R.-B. Johnson, eds., p. 232–242 (Aug. 2005)

T. Kaesebier, H. Hartung, E.-B. Kley, A. Tünnermann

Novel fabrication technique of continuous profiles for microoptics and integrated optics

Optical Fabrication, Testing, and Metrology II, Proc. SPIE Vol. 5965, A. Duparré, R. Geyl, L. Wang, eds., p. 29–39 (in print)





E.-B. Kley, T. Erdmann, P. Triebel, H.-J. Fuchs, B. Horstmann, S. Nolte, A. Tünnermann

Nonlinear resonance effects on thin micro structured aluminum metal gratings by high power fs-laser pulses

AOMATT 2005, 2-5 November 2005 Xian, China

J. Limpert, N. Deguil-Robin, I. Manek-Hönniger, F. Salin, F. Röser, A. Liem, T. Schreiber, S. Nolte, H. Zellmer, A. Tünnermann, J. Broeng, A. Petersson, C. Jakobson
120-W Short-Length Rod-Type Photonic Crystal Fiber Laser

CLEO, Baltimore, USA (2005)

J. Limpert, N. Deguil-Robin, I. Manek-Hönniger, F. Salin, T. Schreiber, A. Liem, F. Röser, H. Zellmer, A. Tünnermann, A. Courjaud, C. Hönniger, E. Mottay
High-power picosecond pulses by SPM-induced spectral compression in a fiber amplifier

OSA Trends in Optics and Photonics Vol. 98, Advanced Solid-State Photonics, p.665 (2005)

J. Limpert, T. Peschel, R. Eberhart, A. Tünnermann

Möglichkeiten und Grenzen der Leistungsskalierung von Faserlasern

Workshop »Neue Technologien – Ausblick in eine wehrtechnische Zukunft« 17. 11. 2005 im BMVg Bonn, organisiert vom Fraunhofer Institut für Naturwissenschaftlich-Technische Trendanalysen (INT)

G. Matthäus, J. Burghoff, M. Will, T. Peschel, S. Nolte, A. Tünnermann
Thermal effects vs. gain in femtosecond laser written waveguides in neodymium doped fused silica

Advanced Solid State Photonics (ASSP), Wien, Österreich (2005)

G. Matthäus, S. Nolte, A. Tünnermann

Generation of powerful terahertz radiation using
a fs fiber laser amplifier at 1060 nm

Deutsch-kanadischer Workshop für Nachwuchswissenschaftler zu den Themen
»Laser in Manufacturing« und »Biophotonik« München (2005)

A.H. Nejadmalayeri, P.R. Herman, J. Burghoff, M. Will, S. Nolte, A. Tünnermann

Femtosecond laser modification of refractive index in silicon

The 8th International Conference on Laser Ablation (COLA), Banff, Canada (2005)

T. Pertsch, R. Iliew, C. Etrich, U. Peschel, M. Augustin, D. Schelle, H.-J. Fuchs,

S. Nolte, E.-B. Kley, A. Tünnermann, F. Lederer

Tailoring of the refractive and diffractive properties of micro-structured dielectrics

EPFL Latsis Symposium on negative refraction: revisiting electromagnetics from microwaves
to optics, page 99 (2005)

T. Pertsch, R. Schiek, R. Iwanow, G. Stegeman, U. Peschel, F. Lederer,

Y. H. Min, W. Sohler

Direct measurement of photonic band structures by second harmonic generation

Conference on Quantum Electronics and Laser Science, OSA Technical Digest,
paper QThK4 (2005)

T. Pertsch, A. Szameit, J. Burghoff, S. Nolte, U. Peschel, F. Lederer, A. Tünnermann

Coupled waveguide arrays in glass by fs-laser writing

12th European Conference on Integrated Optics (ECIO), Grenoble, France (2005)

S. Poyyil Veetil, H. Schimmel, F. Wyrowski

Modeling pulsed beam propagation through homogeneous
and inhomogeneous linear media

SPIE Proc. VOL 5962, Bellingham, 2005, in press





F. Röser, J. Limpert, T. Schreiber, H. Zellmer, A. Tünnermann
High energy ultrashort pulse fiber amplifier without CPA
Photonics West paper 5714-12 (2005)

F. Röser, T. Schreiber, H. Zellmer, S. D. Jackson, A. Tünnermann
Compact high-power Ho-fiber laser at 2 μ
Photonics West paper 5709-38 (2005)

F. Röser, T. Schreiber, M. Will, H. Zellmer, A. Tünnermann
Faser-CPA-System mit 100 μ J Ausgangsenergie in ultrakurzen Pulsen
für Materialbearbeitung
Verhandlungen der DPG, Q12.1 (2005)

F. Röser, M. Will, J. Burghoff, T. Schreiber, S. Nolte, H. Zellmer, A. Tünnermann
High-speed micromachining with ultrashort laser pulses delivered
by an air-core photonic crystal fiber
Proc. ASSP, WB29 (2005)

*F. Röser, M. Will, T. Schreiber, J. Burghoff, S. Nolte, H. Zellmer,
A. Tünnermann, J. Limpert*
High-Speed Micromachining with Ultrashort Laser Pulses Delivered
by an Air-Core Photonic Crystal Fiber
Advanced Solid State Photonics (ASSP), Wien, Österreich (2005)

*F. Röser, B. Ortac, J. Rothhardt, A. Liem, O. Schmidt, T. Schreiber,
J. Limpert, A. Tünnermann*
106 W 220 fs fiber laser system
CLEO Postdeadline Paper Session, CPDB12 (2005)

*F. Röser, B. Ortac, J. Rothhardt, A. Liem, O. Schmidt, T. Schreiber,
J. Limpert, A. Tünnermann*
131 W 220 fs fiber laser system
CLEO-Europe Postdeadline Session II, CP2-5-THU (2005)

H. Schimmel, F. Wyrowski
Diffuser technology for illumination
SPIE Proc. Vol 5962, Bellingham, 2005, in press

H. Schimmel, F. Wyrowski, T. Paul
Concepts for Modern Optics Software
SPIE Proc. VOL 5962, Bellingham, 2005, in press

*T. Schreiber, A. Liem, F. Röser, H. Zellmer, A. Tünnermann, J. Limpert, N. Deguil-
Robin, I. Manek-Hönniger, F. Salin, A. Courjaud, C. Hönniger, E. Mottay*
High-power picosecond pulses by SPM-induced spectral compression
in a fiber amplifier
Proc. SPIE, Vol. 5709, pp. 32-36 in Fiber Lasers II: Technology, Systems and Applications (2005)

T. Schreiber, F. Röser, A. Liem, H. Zellmer, A. Tünnermann
High average power femtosecond parabolic pulse fiber amplifier
OSA Trends in Optics and Photonics Vol. 98, Advanced Solid-State Photonics, p.559 (2005)

*T. Schreiber, F. Röser, J. Limpert, A. Liem, S. Höfer, H. Zellmer, M. Will,
S. Nolte, A. Tünnermann*
High Repetition Rate, High Energy Fiber CPA System for Material Processing
CLEO, Baltimore, USA (2005)





T. Schreiber, F. Röser, A. Liem, J. Limpert, H. Zellmer, A. Tünnermann
High average power femtosecond parabolic pulse fiber amplifier
Proc. SPIE, Vol. 5709, pp. 27-31 in Fiber Lasers II: Technology, Systems and Applications (2005)

T. Schreiber, F. Röser, S. Nolte, H. Zellmer, A. Tünnermann
Polarisationserhaltende photonische Kristallfasern
Verhandlungen der DPG, Q47.1 (2005)

A. Szameit, D. Blömer, J. Burghoff, T. Pertsch, S. Nolte, A. Tünnermann
Nonlinear Waveguide Arrays by Femtosecond Laser Writing in Fused Silica
Nonlinear Guides Waves, Dresden (2005)

*A. Szameit, J. Burghoff, S. Nolte, T. Pertsch, U. Peschel, F. Lederer,
A. Tünnermann*
Hexagonal arrays of fs-laser written waveguides
CLEO/Europe, München (2005)

*H. Trompeter, D. Michaelis, U. Streppel, U. Peschel, T. Pertsch,
A. Bräuer, F. Lederer*
Inhomogeneous waveguide arrays
12th European Conference on Integrated Optics, paper WeB1-3, 100-103 (2005)

*H. Trompeter, U. Peschel, T. Pertsch, F. Lederer, D. Michaelis,
U. Streppel, A. Bräuer*
Photonic Zener tunneling
Conference on Quantum Electronics and Laser Science, OSA Technical Digest, paper QFA2 (2005)

H. Trompeter, U. Streppel, D. Michaelis, A. Bräuer, U. Peschel, T. Pertsch, F. Lederer

Experimental and theoretical investigations on localized states
in waveguide arrays

Integrated Optics: Devices, Materials, and Technologies IX, Proceedings of SPIE Vol. 5728 (2005)

M. Will, J. Burghoff, S. Nolte, A. Tünnermann, F. Wunderlich, K. Goetz

Detailed investigations on femtosecond-induced modifications
in crystalline quartz for integrated optical applications

Photonics West/LASE, San Jose, USA (2005)

M. Will, J. Limpert, T. Schreiber, S. Nolte, A. Tünnermann

Micromachining with ultrashort laser pulses delivered
by an air-core photonic crystal fiber

Photonics West/LASE, San Jose, USA (2005)

F. Wyrowski, H. Schimmel

Lichtquellenmodellierung

Lasertechnik Journal 03/05, Pages 59-63, Weinheim, 2005

F. Wyrowski, H. Schimmel

Nanooptics for high efficient photon management

SPIE Proc. VOL 5962, Bellingham, 2005, in press





■ Activities

Fairs and Exhibitions

World of Photonics – Laser 05 München
Ausstellung Faserlaser, Ausstellung des ZIK »ultra optics«

Offener Tag im Bundeskanzleramt
Ausstellung Mikro- und Nanostrukturierte Optik, Ausstellung des ZIK »ultra optics«®

Lange Nacht der Wissenschaften Jena
Ausstellung Lasertechnik, Ausstellung des ZIK »ultra optics«®

Hochschulrektorenkonferenz, Jena Juni 2005
Präsentation des ZIK »ultra optics«®

Eröffnung von OCORAY in Dresden, Juni 2005
Vorstellung des ZIK »ultra optics«®

Awards

Andreas Tünnermann

Gottfried-Wilhelm Leibniz-Preis 2005

awarded for fundamental work on fiber lasers:

»Faserlaser und miniaturisierte Optik«

Fabian Röser

Student Award Advanced Solid State Photonics 2005

awarded for fundamental work on ultrafast fiber lasers: »Faserlaser«

Ulrike Fuchs

Rhode und Schwarz-Preis 2005

»Best diploma thesis in physics 2005 at FSU Jena«

Thomas Schreiber

»Best Student Presentation Award« Photonics West 2005

Oliver Schmidt

»Best masterthesis in 2005 at FH Jena«





Organizing Activities

Prof. A. Tünnermann

- Rat der Fakultät
- Programme Committee Member IMEKO 2005
- Programme Committee Member Photonics West: Fiber Lasers: Technology, systems and applications 2005
- Symposium Chair Optical Systems Design 2005
- Beirat VDI-Kompetenzfeld: Optische Technologien
- Member of Scientific Advisory Board Optics Communication
- Board Member European Physical Society; Quantum Electronics and Optics Division
- Member of the International Council of the Optical Society of America
- Gutachtertätigkeit für diverse internationale Zeitschriften
- Member of the Board BioCentiv Jena

Prof. F. Wyrowski

- Gutachtertätigkeit für diverse internationale Zeitschriften

Prof. S. Nolte

- Conference Chair: Photonics West/LASE (Commercial and Biomedical Applications of Ultrafast Lasers)
- Gutachtertätigkeit für diverse internationale Zeitschriften

Dr. J. Limpert

- Programme Committee CLEO/Europe 2005: Fiber, Waveguides and Integrated Optics Lasers and Applications
- Gutachtertätigkeit für diverse internationale Zeitschriften

B. Martin

- Rat der Fakultät

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