CeOPP

2012
2013

Center for Optoelectronics and Photonics Paderborn

UNIVERSITÄT PADERBORN
Die Universität der Informationsgesellschaft

Preface

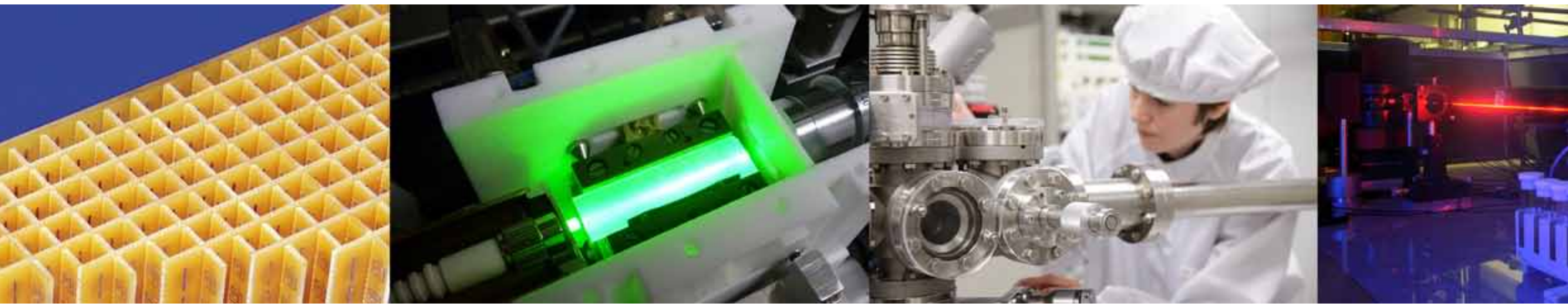
The University of Paderborn is well known as "The University of the Information Society". Corporate Image, mission statement and all university activities aim towards this core competence. With its focus on computer sciences and its applications the University of Paderborn concentrates on the requirements of the Information Society. In accordance with this guiding principle the University of Paderborn perceives itself as a research university.

Optoelectronics and photonics are significant areas of research within our university. With the foundation of the central research facility "Center for Optoelectronics and Photonics Paderborn" (CeOPP) in the year 2006, the joint research activities in the fields of optical technologies became a sustained topical focus of the University of Paderborn. Within the CeOPP, 15 groups from the departments of physics, electrical engineering and chemistry are currently successfully collaborating in research and teaching. They develop novel devices and circuits based on emerging technologies in optoelectronics and photonics, and demonstrate their performance in sophisticated device applications. With the opening of the new building for optoelectronics, integrated optics, and photonics in 2006, excellent lab and cleanroom facilities were made available to our scientists. Another important prerequisite for success is a good mixture of highly qualified young as well as experienced researchers, who guarantee constant progress and improvement. The University of Paderborn intends to continue to promote and set on this field of research through further recruitments of qualified researchers. The recently established DFG Research Training Group "Micro- and Nanostructures in Optoelectronics and Photonics" (GRK 1464) is a preeminent example of the joint and coordinated research and of the commitment to teach and support young academics in this field.

It is a great honor that the research results of optoelectronics and photonics can be presented in this CeOPP brochure to the public today.

Prof. Dr. Nikolaus Risch, President of the University of Paderborn

October 2011



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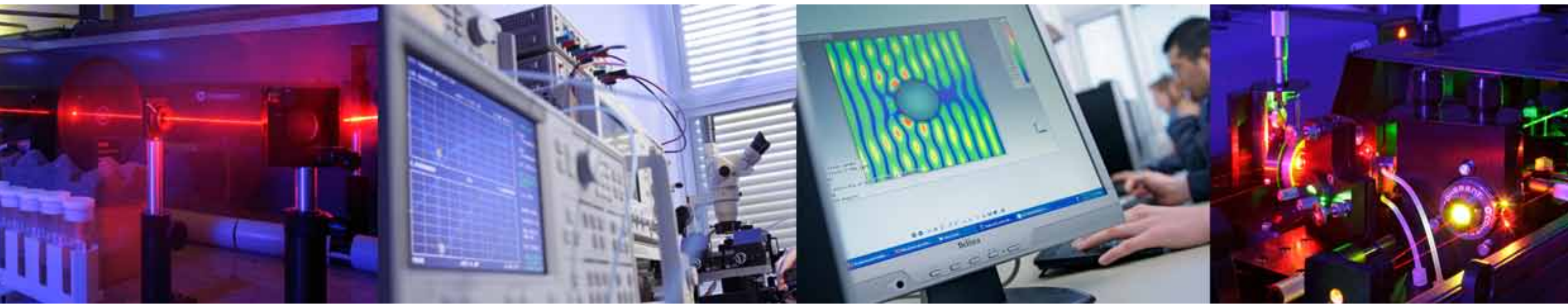

About CeOPP

Since 1989 the University of Paderborn is constantly promoting research and development in the fields of modern optical technologies. Over the years, this topical focus within our University was continuously developed into the fields of optoelectronics, photonics, and integrated optics, in accordance with the mission statement of the University of Paderborn as "University of the Information Society". An important prerequisite for this concept was the formation of an interdisciplinary group of designated researchers from the departments of physics, electrical engineering and information technology, and chemistry. Already in 1997 the Deutsche Forschungsgemeinschaft (DFG) started to support the activities in Paderborn with the establishment of the coordinated research unit "Integrated Optics in Lithium Niobate". In the year 2006, the central research facility "Center for Optoelectronics and Photonics Paderborn" (CeOPP) was founded on the basis of initially ten designated research groups. In the same year, the new building for optoelectronics, integrated optics, and photonics became available for the CeOPP researchers. Excellent clean room facilities, as well as top quality lab and office space can since then be used for corporate research and development. The jointly used clean room lab space provides an ideal seed for interdisciplinary research projects. We are therefore very pleased that 2008 marks the starting point of our new joint research activities on "Micro- and Nanostructures in Optoelectronics and Photonics" within the framework of the recently established DFG Research Training Group GRK 1464.

For teaching and education, the interdisciplinary structure of the CeOPP offers unique opportunities for Bachelor-, Master-, and PhD-students to acquire a broad and profound knowledge in optoelectronics and photonics, which are regarded as the enabling technologies of the next century. No matter whether the individual interests are oriented towards fundamental or applied aspects, towards theory, experiment, or technology, the appropriate lecture or internship is readily found in the Bachelor and Master programs of our departments. The mission of the CeOPP to promote the best possible professional qualification for the students is supplemented by the organisation of graduate lectures about hot topics in the field, presented by distinguished external speakers.

By now, 15 designated research groups are member of the CeOPP. Together they cover important areas of the innovative optical technologies of today, as presented to you in this brochure.

Prof. Dr. Artur Zrenner, Chairman of CeOPP

October 2011

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Optical Communication and High-Frequency Engineering

Prof. Dr.-Ing. R. Noé

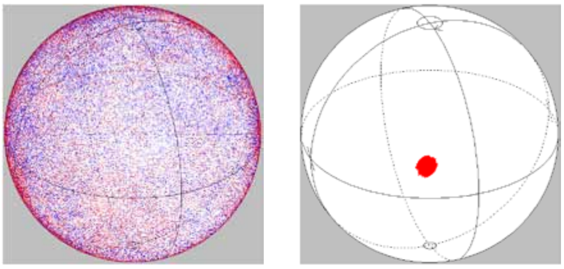
Optical communication transmits information for internet and telephone. At 1.55 µm wavelength the attenuation of optical fibers is so small that after 100 km there is still 1/100 of the transmitted optical power available. The bandwidth is about 1/5 of the light frequency, roughly 40 THz. This is ~1000 times as much as in the whole radio frequency spectrum currently in use. About 4 THz can be utilized very cost-efficiently, by means of optical amplifiers. The superb fiber properties have made internet and low-cost telephony possible. The growth of data communication is enormous, on the order of 50% per year. Network operators and their suppliers want to utilize existing fiber links most efficiently. This defines our research topics: Fiber distortions, i.e., polarization transformations, polarization mode dispersion and chromatic dispersion must be compensated. Advanced optical modulation formats such as quadrature phase shift keying combined with polarization division multiplex allow to multiply optical information density. Phase-noise tolerant coherent receivers provide best performance and allow to equalize the fiber distortions in the electronic domain.

Equalization of Fiber Distortions

Using DQPSK combined with polarization division multiplex, we have transmitted 5.94 Tbit/s (5.940.000.000.000 bit/s) over 324 km of fiber in the optical C band alone (world record until 2007).

Just like a short earthquake excites a distant seismometer for a longer time, short data pulses are temporally broadened in an optical fiber by chromatic dispersion (CD). For compensation purposes we measure CD in a low-cost setup. The pump current of the transmitter laser is slightly modulated at 5 MHz. This causes an optical frequency modulation of a few 100 MHz and hence a pulse arrival time modulation in the presence of CD. At the same time the light power is modulated by about 1%, which provides a reference for synchronous detection. The setup is able to detect periodically repeated light pulse arrival time changes with an accuracy of 100 attoseconds (0,000.000.000.000.000.1 s).

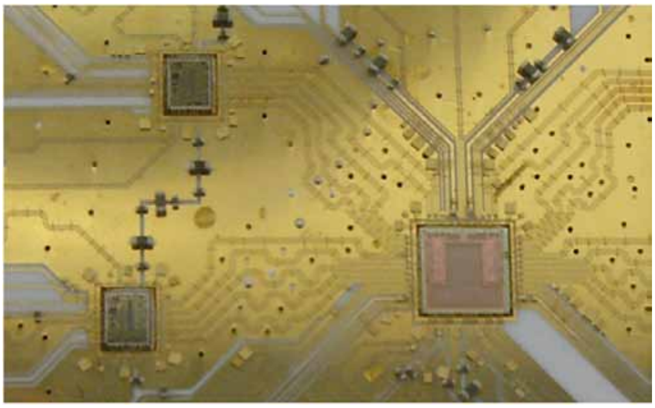
No control **Under control**



Polarization states on Poincaré sphere without (left) and with (right) endless polarization control.

If the fiber core cross section happens to be elliptical rather than circular then the light polarizations corresponding to the ellipse axes propagate with different velocities. This polarization mode dispersion (PMD) also broadens light pulses. We have proposed and the Integrated Optics group has realized an integrated-optical $LiNbO_3$ component by which we compensate PMD. This approach is much more powerful than competing ones, since inside the component several optical polarization controllers are integrated.

PMD varies over time as a function of fiber temperature and handling. Simpler than this, polarization-sensitive optical transmission schemes require an optical polarization control system at the receive end, because otherwise some or most information will be lost. We have realized endless optical polarization control, i.e., with unlimited tracking range, again using $LiNbO_3$ components. IIn this context we have achieved an unrivaled polarization tracking speed of 100 krad/s on the so-called Poincaré sphere. This corresponds to about 8000 complete polarization revolutions per second.



Ceramic board with analog-to-digital converters and „syn-QPSK" signal processing component.

Optical Modulation Formats

We use 2 orthogonal polarization directions and 4 phase states to transmit in each data symbol 16 different states rather than the traditional 2 (light on/off).

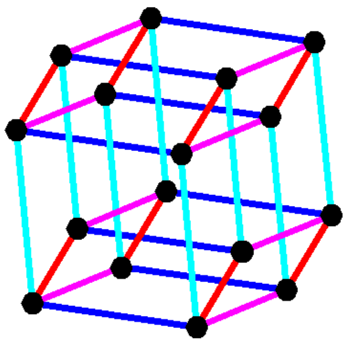
Using this differential quadrature phase shift keying (DQPSK) scheme we have set up a capacity world record in 2005, the transmission of 5,94 Tbit/s (5.940.000.000.000 bit/s) over 324 km of fiber in four spans of 81 km each. At the receive end, polarizations were demultiplexed, and then the data was demodulated in interferometers and regenerated. Recently we have also used our fast endless optical polarization control system for polarization demultiplex. This was successfully tested by Ericsson in the fiber network of Deutsche Telekom.

As an alternative, the 4 phase states can be synchronously demodulated. To this purpose, the light of an unmodulated local laser is superimposed to the received light, thereby creating interferences which depend on the data. Such a coherent optical receiver improves sensitivity and allows for a cost-effective signal equalization, namely against the three above-mentioned fiber distortions.

One key problem is laser phase noise. We have developed a carrier recovery scheme that is extremely phase noise tolerant. Using this scheme we have demonstrated the worldwide first realtime synchronous QPSK transmission with standard lasers. We have then added polarization division multiplex and an automatic electronic polarization control, again as the first worldwide in realtime. The system meanwhile runs with a tracking speed of 40 krad/s and tolerates also polarization-dependent loss. These efforts were funded by the European Commission in project „synQPSK".

For signal processing we have developed a microelectronic 5-bit analog-to-digital converter for 12.5 GHz sampling frequency in SiGe technology and, together with Prof. Ulrich Rückert, a CMOS chip.

Recently, we have developed an enhancement of the QPSK carrier recovery algorithm which makes it usable for quadrature amplitude modulation formats such as 16-QAM. The latter will allow to double information density once more to 8 bit/symbol. We have also implemented this algorithm in an FPGA and conducted the worldwide first realtime transmission of synchronous optical 16-QAM with large phase noise tolerance.



Projection of a hypercube with 16 optical "synQPSK" symbols in the 4-dimensional space of two quadratures and two polarizations onto a 2-dimensional plane.

Equipment

- 40 DWDM lasers
- Tunable lasers
- 40 and 10 Gbaud optical test beds
- Coherent optical test
- 50 GHz oscilloscopes
- 8 GHz realtime oscilloscope
- 110 GHz network analyzer
- Microwave and millimeter wave generators
- Optical spectrum analyzers
- Optical wavemeters
- 420 km of optical fiber
- Recirculating loop switch
- Erbium-doped fiber and Raman optical amplifiers
- Fixed and variable optical dispersion compensators
- Polarimeters
- Electrooptic polarization controllers
- Interferometers
- Optical fiber splicers
- Semi-automatic wedge bonder
- Climate chamber
- Microscopes
- Workstations
- RF and IC design software
- Optical system simulation software

Group Members

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- Mohamed El-Darawy
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- Saleh Hussin
- Omar H.A. Jan
- Benjamin Koch
- Dr.-Ing. Vitali Mirvoda
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