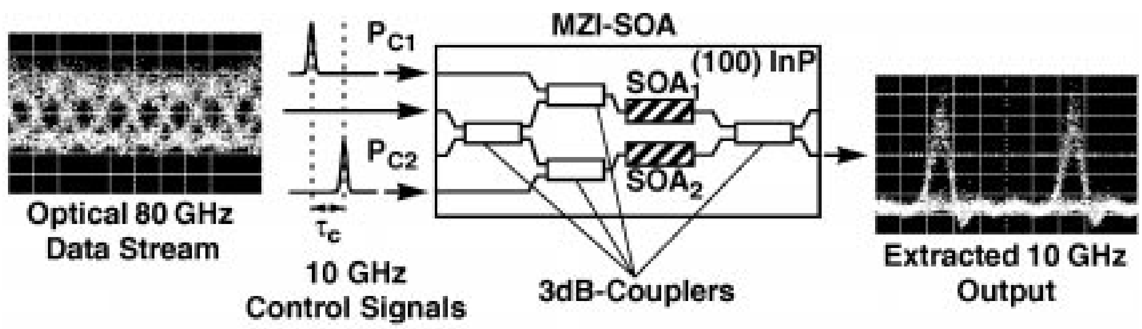
MICROELECTRONICS AND OPTOELECTRONICS LABORATORY



Optically controlled 80 Gb/s to 10 Gb/s demultiplexing of optical signals using monolithic indium phosphide waveguide Mach-Zehnder Interferometer (MZI) with semiconductor optical amplifiers (SOA's) in its arms.

Closely spaced control pulses (P_{C1}, P_{C2}) cause gating and switching through refractive index changes and gain saturation of optical amplifiers at picosecond speeds far beyond the carrier recovery times of the amplifiers.

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RESEARCH AND TEACHING SUMMARY

The **Microelectronics and Optoelectronics Laboratory** has as its base a three-five compound semiconductor device technology and fabrication facility. It is equipped with metal-organic vapor-phase epitaxy, plasma etchers, evaporators, contact lithography, all in clean flow boxes, as well as computer aided design and characterzation tools. Optoelectronic waveguide components, switches, optical amplifiers, photodetectors, heterobipolar transistors and electronic circuits are realized mainly in indium phosphide compounds. Quantum-well and quantum-wire structures for our own as well as for the needs of other groups are grown in gallium-aluminium-arsenide.

Additional devices and components, like optical waveguide filters and electronic transmitter and receiver circuits for highly parallel optical interconnects are conceived, designed and characterized here but fabricated in commercial silica on silicon transistor foundries.

A complementary activity in single-mode optical waveguide component-to-fiber alignment and packaging capability allows us to realize entire optical and electronic component modules for system applications.

Current research activities of the Microelectronics and Optoelectronics group include:

- Monolithic indium phosphide optical waveguide switches in Mach-Zehnder interferometer configurations for fiber optical communication.
  Electrically controlled versions exploit the Franz-Keldysh effect for the switching of 1.55 micrometer wavelength signals.
  Optically controlled Mach-Zehnder interferometers with semiconductor optical amplifiers in their arms, switch, demultiplex and wavelength-convert signals at 10, 40 and 80 Gbit/s. Experimental and theoretical studies reveal subpicosecond physical effects and picosecond sampling gate capabilities.
- Thermally activated silica on silicon space switches with high on-off ratios and millisecond speeds.
- Semiconductor optical amplifiers for 1.3 and for 1.5 micrometer wavelengths.
- Studies of non-linear effects and of four wave mixing in semiconductor optical amplifiers.
- Optical multichannel filters featuring planar SiO_2/Si phasar-arrays for wavelength division multiplex-communication.
- Special transmitter and receiver electronics in indium-phosphide heterobipolar transistor and in silicon-complimentary transistor (CMOS) technology for high-speed fiber optical communication and high throughput parallel optical interconnect developments.

The **Thin Film Physics Group** is active in the physics and the development of compound semiconductors, such as PbTe/PbSnSe, CuInSe, CuGaSa, CdTe/Cds for infrared detection and solar cell applications. A highlight are the GaAs/CaF2 multilayer stacks for extremely wide-bandwidth Bragg reflectors that are a key for the generation of femtosecond pulses with titanium sapphire lasers (see Prof. U. Keller).

Both, the optoelectronics and microelectronics physics and device group and the thin film physics group benefit from close collaboration in Swiss and international research projects. These collaborations include projects of the European Union, ACTS- Highway, Open, Keops, Cobnet, Wotan, ESPRIT-Spiboc, Oiic, Rodci, Joule, ESA and COST-Telecommunications as well as Swiss optics research and national foundation projects. There is active collaboration with Swiss university and industry groups and with research and development groups of major European communication companies and operators and selected universities.

Teaching activities include advanced courses covering physics, technology and devices of optoelectronics and electronics, thin films and fiber optical communication, as well as basic introductory courses in electronics for both physics and electrical engineering students. A speciality is the hands-on device fabrication courses associated with the physics and technology coarse on electron devices.

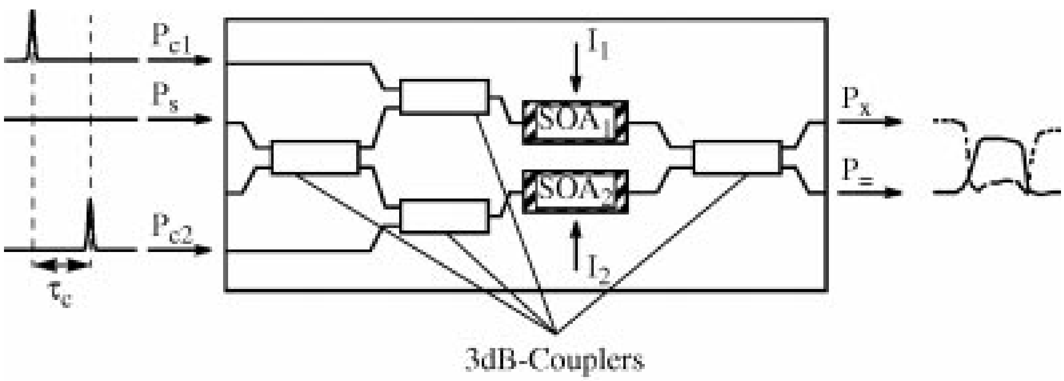
It is a pleasure to thank the Swiss Federal Government with its Nationalfonds (NF), Kommission für Technologie und Innovation (KTI), Bundesamt für Bildung und Wissenschaft (BBW), the Swiss Federal Institute of Technology and our Industrial Partners for their interest and continuous support.

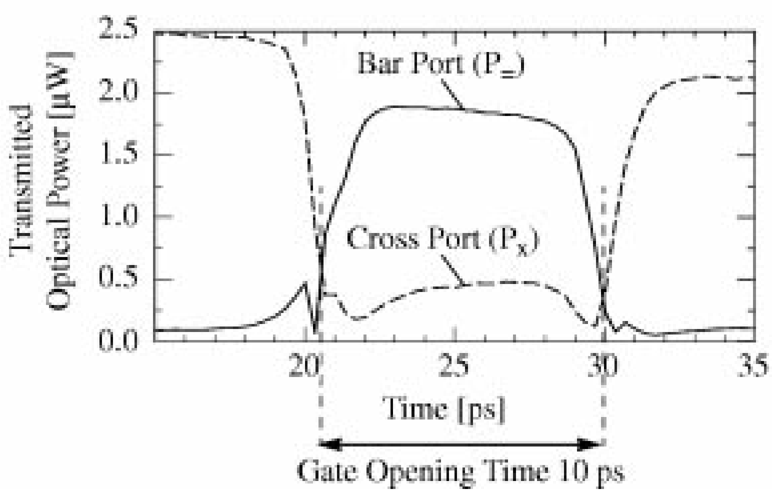
All-Optical Mach-Zehnder Interferometer Switches and Demultiplexers

R. Hess, M. Bitter, M. Caraccia-Gross, W. Vogt, E. Gamper, H. Melchior

Optical switches, that are controlled by optical pulses hold promise for extensions of switching speeds beyond the limits of current electronics. We have realized Mach-Zehnder interferometers (MZI) type indium-phosphide switches with semiconductor optical amplifiers (SOA's) in their arms. If symmetrically biased, input signals (P_s) are directed to the cross port (P_x). Upon application of a short (ps) control pulse P_{c1}, SOA_1 is disturbed, changing its gain and its refractive index, causing signal pulses to switch from cross port to bar port ($P_=$). A second control pulse (P_{c2}), applied shortly (τ_c) thereafter, switches the signals back to the cross port (P_x). Through superposition of two closely spaced control pulses, the signals passing through the MZI-SOA are, thus, switched from port to port. These optically controlled MZI-SOA's are suitable for high-speed optical demultiplexers, optical sampling gates and wavelength converters.

A demonstration of 10 ps gating obtained with an MZI-SOA is shown below. Two hundred femtosecond control pulses (P_{c1}, P_{c2}) spaced (τ_c=10 ps) and repeated at 80 MHz from a 1.53 µm Spectra Physics laser system control the MZI-SOA. By means of a pump probe technique the switching from the cross (P_x) to the bar ($P_=$) and gating is demonstrated.

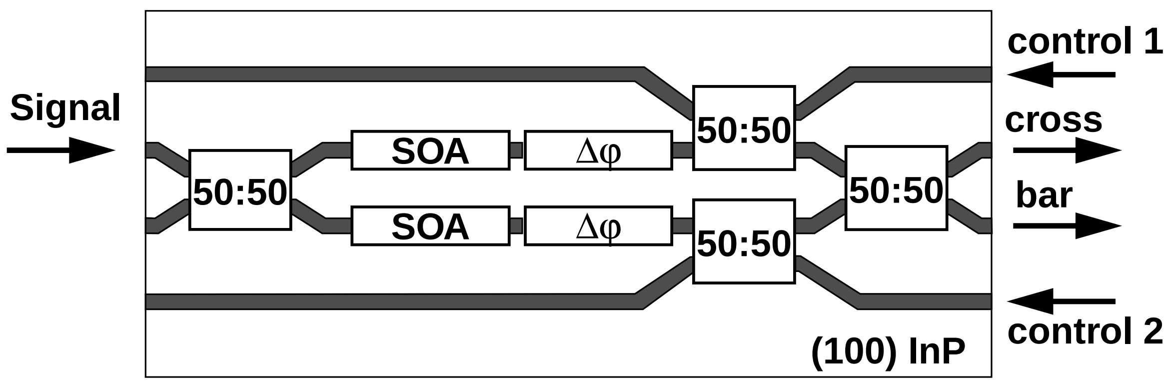




Monolithically Integrated Ultra-High Speed All-Optical Indium Phosphide Waveguide Switches and Demultiplexers

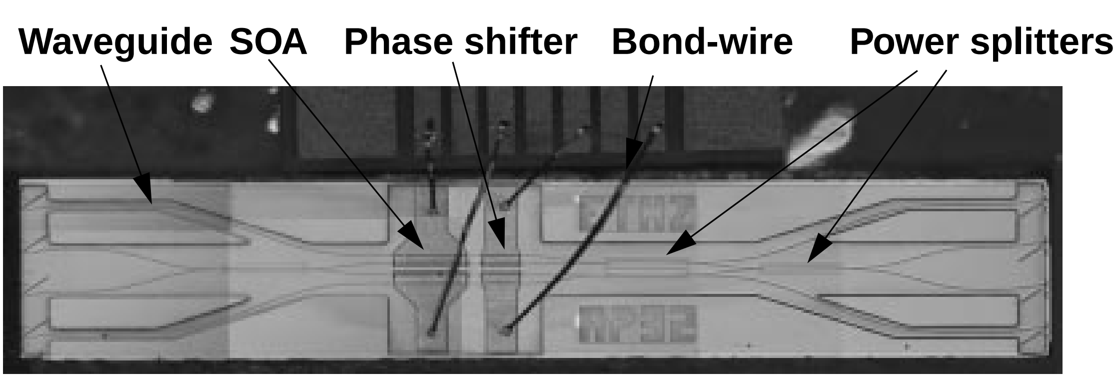
E. Gini, W. Vogt, E. Gamper

All-optical switches use optical controls to switch the light-path of signals between the bar and cross state. Major applications for these components are optical demultiplexing of high bit-rate signals with add-drop function and wavelength conversion for wavelength division multiplexed (WDM) networks. Switching is done by introducing optical control-pulses into the arms of a Mach-Zehnder interferometer (MZI) that contain SOAs and phase-shifting elements. The control pulses generate refractive index changes that alter the optical length of the arms in the MZI, leading to constructive interference either in the bar or in the cross output waveguide. The InP device is built from a number of different components: semiconductor optical amplifiers (SOA), phase shifters (Δφ), passive single mode waveguides, and power splitters (50:50). A schematic view of the device is shown below.



For the monolithic integration of these components we have developed a process using multiple-step low pressure metal-organic vapor phase epitaxy, in combination with wet and dry etching techniques. Pyralin is used for insulation of the electron-beam evaporated and electroplated electrical contacts.

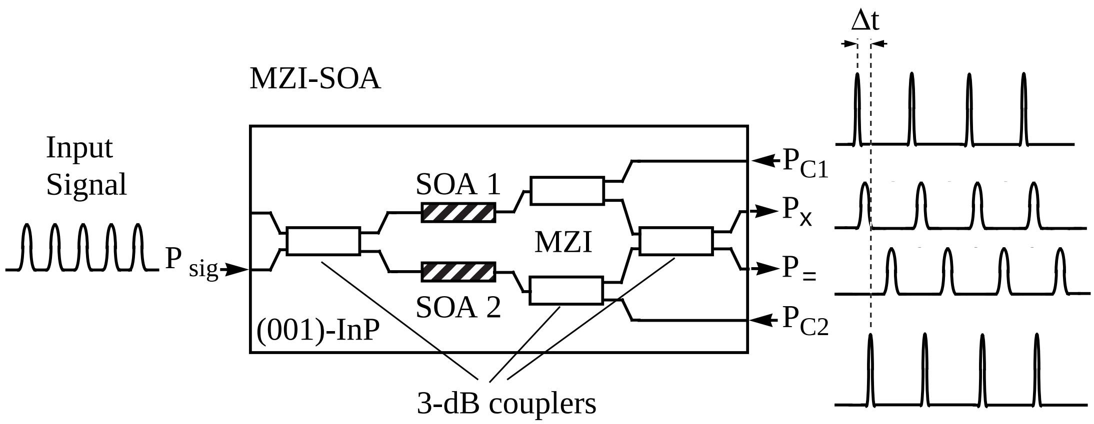
The photograph below shows a mounted and bonded all-optical switch with two SOAs followed by two phase shifters.



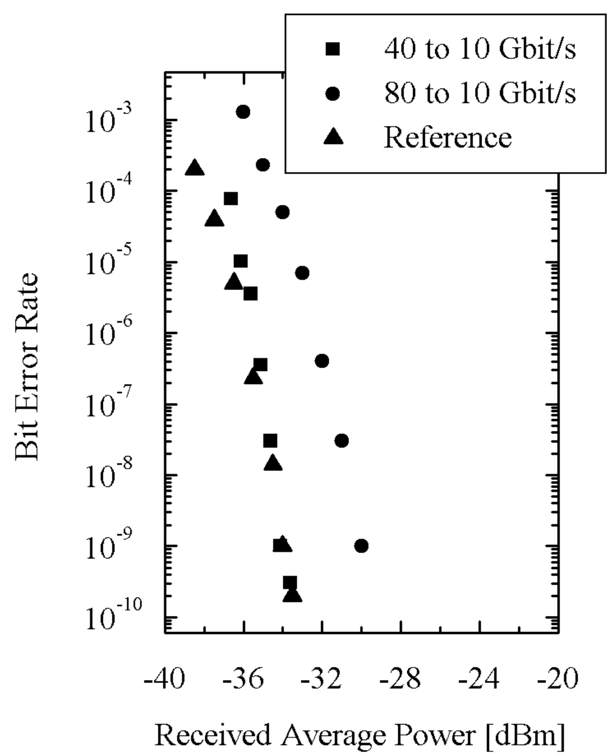
All-Optical 80 to 10 Gbit/s Demultiplexing using a Mach-Zehnder Interferometer with Semiconductor Optical Amplifiers

R. Hess, M. Dülk, W. Vogt, E. Gamper, E. Gini, P. A. Besse, H. Melchior

The demultiplexing operation relies principally on data signal phase and gain changes induced by gain and refractive index changes in the two semiconductor optical amplifiers (SOA's) monolithically integrated in a waveguide Mach-Zehnder interferometer (MZI) through properly synchronized optical control pulse sequences (P_{C1} and P_{C2}). The differential injection of two delayed (Δt) control pulse sequences allows to overcome the limitations imposed by the optical modulation bandwidth of the SOA's, which is of a few GHz. The layout of the device used for the experiments is shown below.



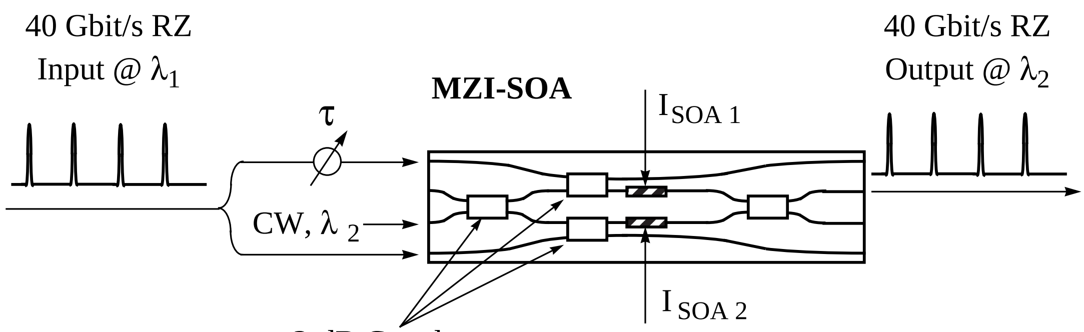
The excellent performances of the MZI-SOA device operating at 1.55 µm are demonstrated by error-free all-optical demultiplexing of 80 Gbit/s random data signals. The bit-rate flexibility of the MZI-SOA is demonstrated by penalty-free all-optical demultiplexing of 40 Gbit/s data streams into 10 Gbit/s streams. Bit-error curves are shown on the right. The same bit error rate performances are obtained for an input power of the data signal ranging between -15 and +2 dBm (17 dB dynamic range). Injection currents for the SOA's are 234 and 247 mA respectively and the control powers for P_{C1} and P_{C2} are +5 dBm, measured in the fibers.



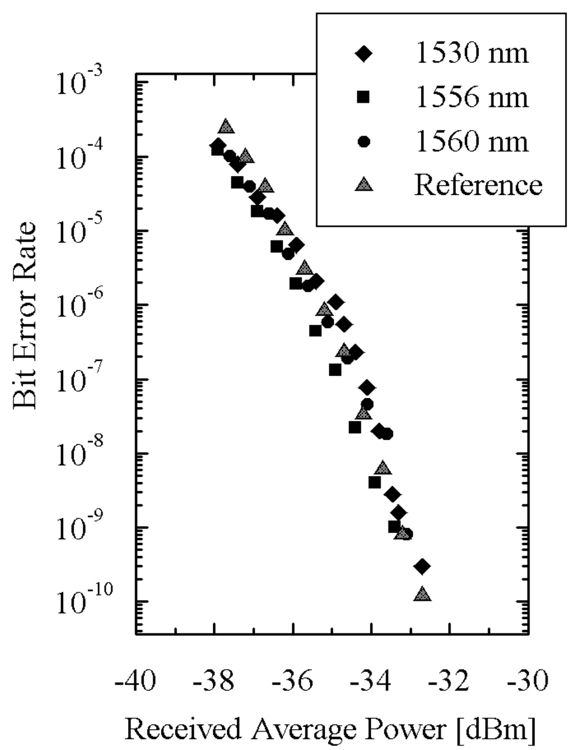
All-Optical Wavelength Conversion for RZ-Signals using High-Performance Mach-Zehnder Interferometer

R. Hess, M. Dülk, W. Vogt, E. Gamper, E. Gini, P. A. Besse, H. Melchior

The operation principle of the all-optical wavelength converter relies on the differential control scheme, which allows to overcome the bandwidth limitations of the semiconductor optical amplifiers (SOA's): the 40 Gbit/s RZ-signal is split in two fibers of approximately the same length, one of them including an optical delay (τ) to fine adjust the synchronisation of the bit pattern sequence. The device used for the experiments is shown below. It consists of single-mode quaternary InP-waveguide Mach-Zehnder interferometer (MZI) with polarization insensitive and low-reflection SOA's and 50:50 % multi-mode interference couplers (MMI) as 3-dB couplers. Device dimensions are 6.5 x 1.5 mm.



System experiments with the MZI-SOA demonstrated penalty-free wavelength conversion of 40 Gbit/s data streams, possible over 30 nm. Other features: no pattern dependant effects are presents, i. e. the bit-error rate (BER) values do not depend on the bit sequence of the input signal; it is possible to obtain both RZ and NRZ output formats by simply tuning an optical delay; no blocking effects present i. e. the device can convert at the signal wavelength (1556 nm for the measurements reported here). BER curves for different wavelengths, with a CW input at 1540 nm are shown on the right.



All-Optical Demultiplexing: Modeling

M. Caraccia-Gross, H. Melchior

A model has been developed to describe all-optical operations of monolithic integrated Mach-Zehnder interferometers (MZI) with semiconductor optical amplifiers (SOA) in their arms. In MZI-SOA's the power $P_{1,2} = G_{1,2}P_{in}$ and the phase $\Phi_{1,2} = \Phi_{in} + \Delta\Phi_{1,2}$ of the data signal at the ouput of the SOA's is balanced by using control pulses which modify the optical total gain $G_{1,2}$ as well as the refractive index in the SOA's and determine the way the data signal recombine in the last coupler via the relation

$$P_{=,x} = \frac{1}{2}\{G_1 + G_2 + 2\sqrt{G_1G_2}\sin(\Phi_1 - \Phi_2)\}P_{in} \equiv T_{=,x}P_{in}$$

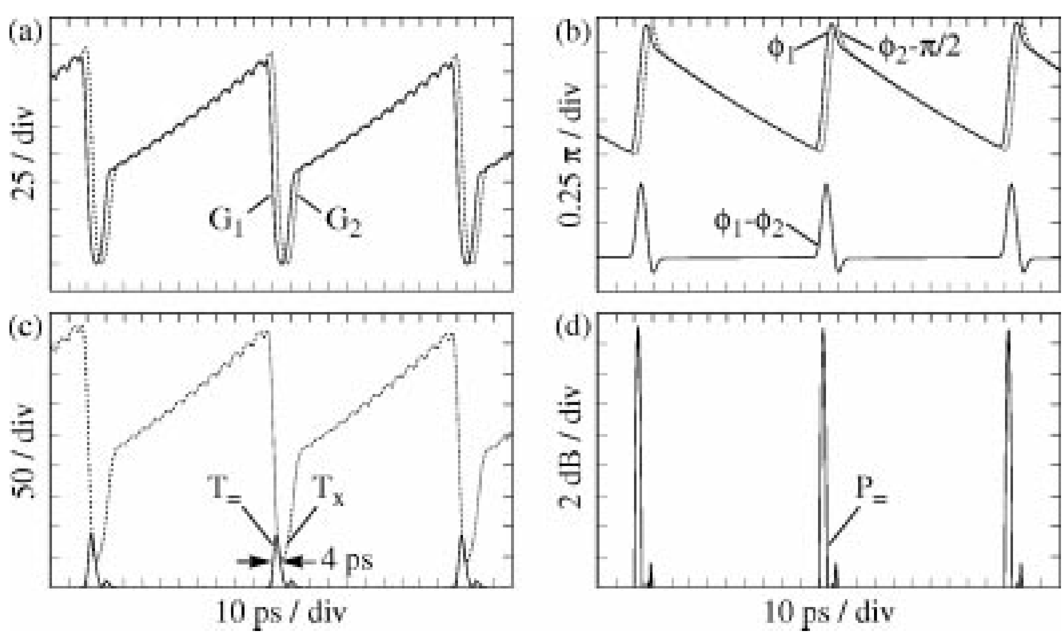
The pulse propagation through the SOA's is calculated with the help of the following rate equations for the power, the phase and the carrier density:

$$\frac{\partial P}{\partial z} + \frac{1}{v_g}\frac{\partial P}{\partial t} = \left\{\frac{\Gamma a(N - N_0)}{1 + (\varepsilon_{CH} + \varepsilon_{SHB})P_{tot}} - \alpha_{int}\right\}P$$

$$\frac{\partial \Phi}{\partial z} + \frac{1}{v_g}\frac{\partial \Phi}{\partial t} = -\frac{1}{2}\Gamma a(N - N_0)[\alpha_N - (\alpha_{CH}\varepsilon_{CH} + \alpha_{SHB}\varepsilon_{SHB})P_{tot}]$$

$$\frac{\partial N}{\partial t} = \frac{I}{qV} - R(N) - \frac{\Gamma a(N(z,t) - N_0) \cdot P_{tot}}{h\omega_0(1 + (\varepsilon_{CH} + \varepsilon_{SHB})P_{tot})}$$

Simulations of 80 to 10 Gbit/s demultiplexing conform with experimental results and prediction of the device performances at higher bit rate or with modified MZI-SOA (with phase-shifters and asymmetrical couplers) has been fulfilled. In the figure below we show predicted 160 to 10 Gbit/s demultiplexing.



Simulations: (a) gain dynamics in the SOA's, (b) optical data phases at the SOA's output, (c) MZI-SOA switching window and (d) demultiplexed data signal for 160 to 10 Gbit/s demultiplexing.

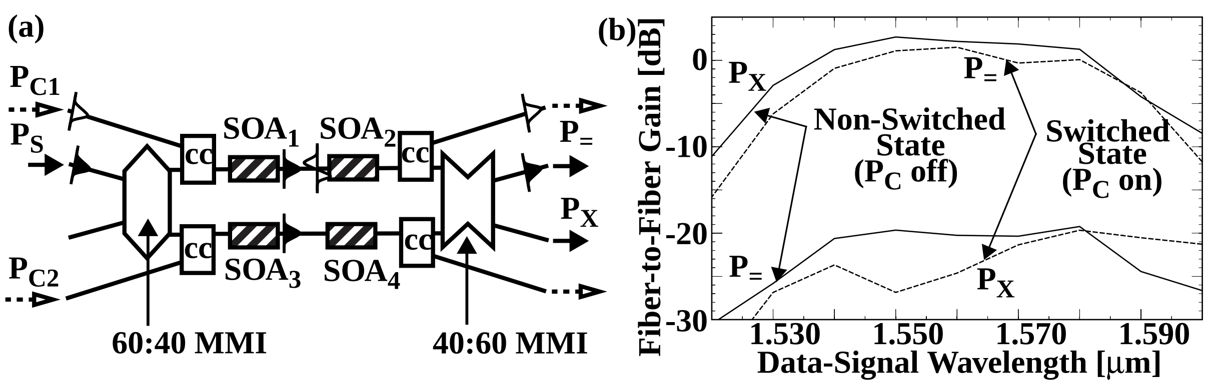
Cascadable All-Optical Space Switches with High and Balanced Extinction Ratios

J. Leuthold, E. Gamper, M. Dülk, P.A. Besse, J. Eckner, R. Hess and H. Melchior

Future optical time division multiplexing systems require cascadable high speed switches and demultiplexers with high extinction ratios.

We have theoretically shown and experimentally demonstrated that asymmetries are necessary to improve the extinction ratios of all-optical Mach-Zehnder Interferometer space switches. In addition we have introduced new MMI-couplers that convert the control-signal into a higher order mode while coupling it into the signal path of the fundamental mode data-signal. With that trick the control- and data-signals can be easily separated after signal processing rendering the devices cascadable. The large optical bandwidths of these so called MMI-converter-combiners were theoretically predicted and experimentally testified.

The all-optical space switch, shown in the figure delivers high and balanced extinction ratios over a large wavelength range. The device comprises two asymmetric multi-mode interferometer (MMI) couplers for data-signal splitting of (P_S), four semiconductor optical amplifiers (SOA's) on the MZI-arms providing the nonlinearities for switching and four MMI-converter-combiners (cc), that are used to introduce and to extract the first order mode control-signal ($P_{C1,2}$). In the absence of the control-signals the data-signals are directed to the cross-port (P_x). To switch the signals into the bar output ($P_=$), control-signals are introduced through the MMI-converter-combiners (cc) to provide in the MZI the necessary phase-shift of π for switching.



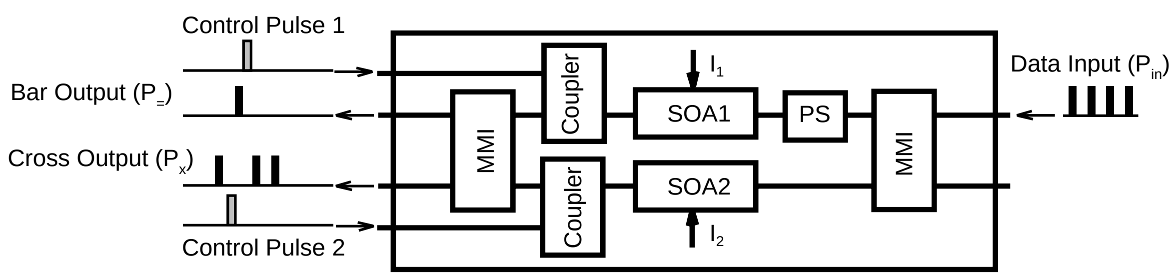
(a)All-optical MZI-SOA switch with asymmetric MMI-splitters to provide high and balanced extinction ratios. A dual order mode configuration is used, where data- and control-signals, coupled in through the MMI's (cc), propagate as zero and first order modes. (b) Extinction ratios of the switch, exceeding 20 dB in the non-switched (solid lines) and switched state (dashed lines) over a large wavelength range.

Dynamic Analysis of Mach-Zehnder Interferometer Semiconductor Optical Amplifier All-Optical Switches for Balanced Switching

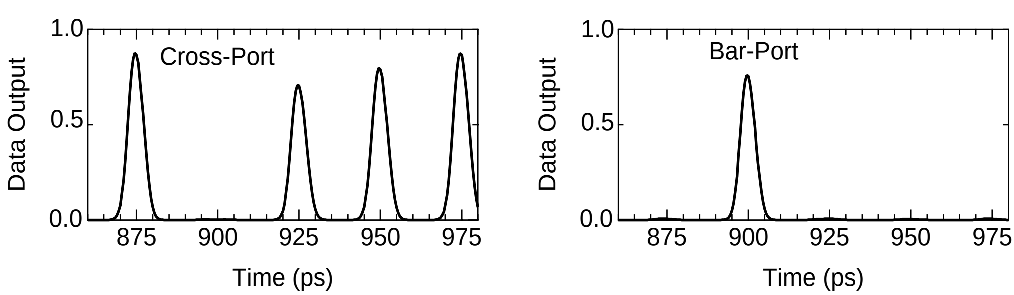
Ken Morito, J. Leuthold and H. Melchior

All optical switches are expected to be key devices in future high capacity optical time division multiplex systems. Monolithically integrated Mach-Zehnder interferometer type all optical switches with semiconductor optical amplifiers (SOA's) in their arms have been developed for high speed switching. 40 to 10 Gbits/s demultiplex (DEMUX) experiments were demonstrated using a differential control scheme. However, the gain in SOA's brings about complicated switching characteristics because transmission characteristic of these integrated interferometric switches with SOA's is determined not only by phase but also by gain. As an example, unbalanced extinction ratios for both switching ports were observed. To improve the unbalanced extinction ratio, asymmetrically biasing the two SOA's was proposed and the balanced extinction ratios were demonstrated in the experiment with a CW data signal.

We have examined the dynamic switching characteristics of MZI-SOA type all optical switches under high speed operation in a time-domain large-signal analysis. Uniform data output powers and high extinction ratios were found for all-optical switches with asymmetrically biased SOA's.



Configuration of MZI-SOA all optical switch. The data signals injected from the input port are directed to the cross-port or the bar-port depending on the phase difference between the two SOA's. The phases in the MZI configuration can be changed by properly adjusting the injection times between the two control pulses.



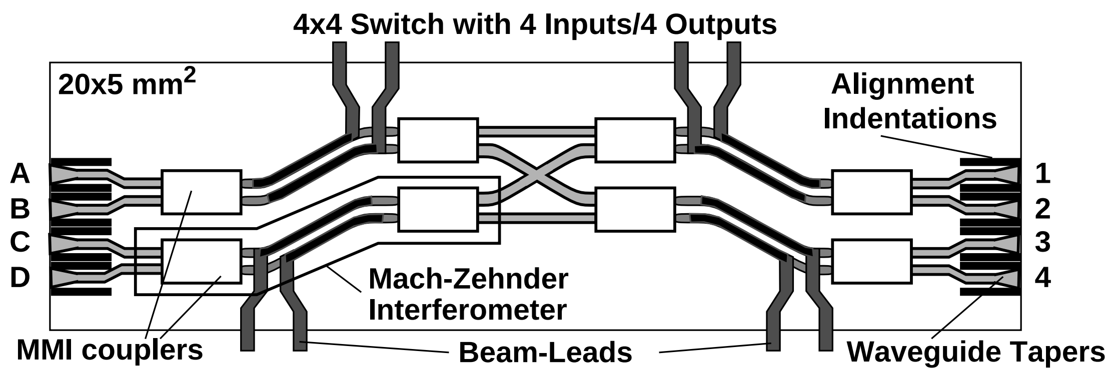
Switching characteristics for the cross and bar port under 40 to 10 Gbits/s DEMUX operation. Both almost uniform output powers and balanced high extinction ratios are obtained by asymmetrically biasing the SOA's.

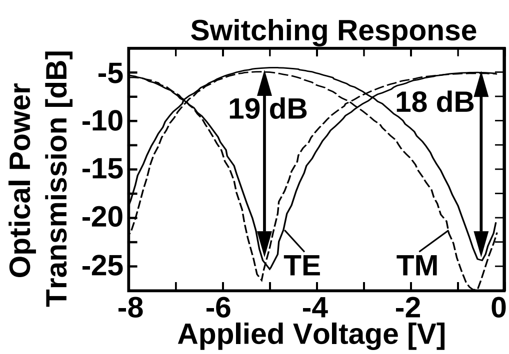
Optical Space Switches Electrically Controlled for Fiber Optical Communication

R. Krähenbühl, W. Vogt, W. Hunziker, H. Schneibel, and R. Bauknecht.

Electrically controlled optical space are key components for use in practical optical communication networks, where they can perform fast switching, rerouting and channel add-drop functions.

We realized InGaAsP/InP optical waveguide switch matrices, configured as four switch units in a two stage architecture with four optical inputs and four optical outputs. These switch matrices consist of four 2x2 Mach-Zehnder interferometer type space switches, exploiting the Franz-Keldysh electro-optic effect in a specially oriented waveguide configuration to achieve polarization insensitivity. To minimize the overall losses, tapered input and output waveguides are integrated with the switches and combined with self-aligned lensed fibers on a V-grooved silicon motherboard. For high-speed operation the switch matrix is interconnected with high-speed InP-HBT driver electronics. The best fully packaged switch module in a two-by-two cascaded configuration with four fiber inputs and four fiber outputs reach record low fiber-to-fiber losses of less than 6 dB in best and 7 dB in all channels. On-state polarization sensitivity is less than 0.5 dB and on-off ratios >15 dB in regular and >30 dB in dilated arrangements, both maintained over 30 nm throughout the 1550 nm wavelength range. Full turn-on and turn-off times of these switches are below 200 ps.





Wavelength of operation		1550 nm
Fiber-to-fiber insertion loss		5-7 dB
Polarization sensitivity		±0.5 dB
Optical on-off ratios	non dilated	>15 dB
	dilated	>30 dB
Spectral bandwidth		30 nm
Switch rearrangement time		<300 ps
Operational voltage	5 Volt	

Optical space switch matrix in monolithic four switch arrangement. Polarization-insensitive operation is provided by means of specially oriented waveguide electrodes that exploit the Franz-Keldysh effect.

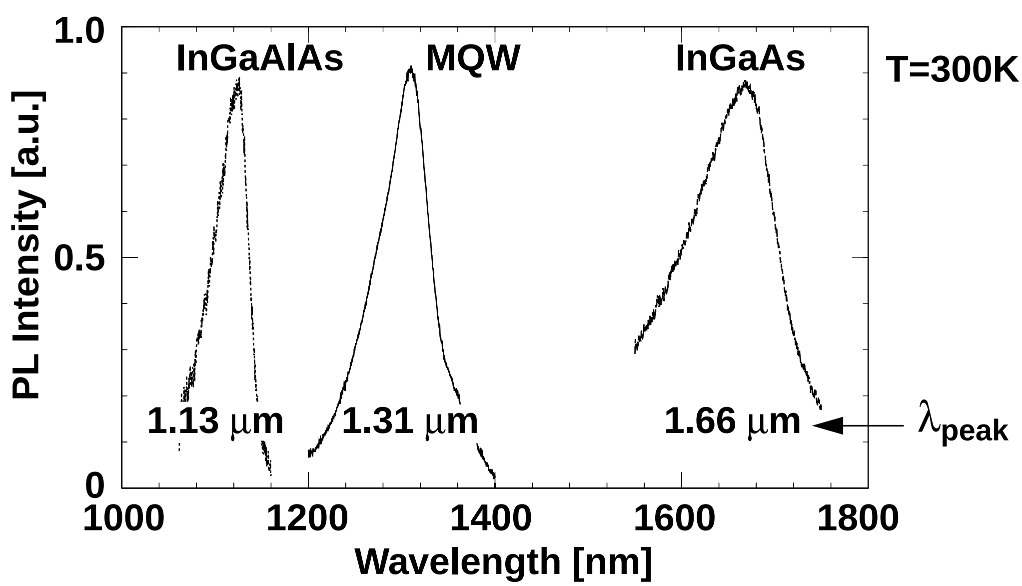
Low-Dimensional Semiconductor Nanostructures for Active and Nonlinear Optoelectronic Devices

E. Gini, L. Alimkulowa, R. Bauknecht, H. Melchior

This is a collaboration project between the group of Prof. E.Kapon at the Institute of Micro- and Optoelectronics at EPFL, our group and CNET in Bagneux in France. The target is to develop low-dimensional quantum confined structures that enable unique optical properties to be obtained for applications in optical and optoelectronic devices. Quantum wires and quantum dots based on III-V semiconductor compounds will be prepared utilizing self-ordering epitaxial growth mechanisms during low-pressure metal-organic vapor phase epitaxy (LP-MOVPE).

As an initial step we have optimized the lattice matched growth of planar quaternary InGaAlAs and ternary InAlAs layers on InP. Targeted bandgap energy of InGaAlAs was 1.1 eV. The incorporation of dopants was studied and calibrated for n-type (Si) as well as for p-type (Zn) doping. $In_{.53}Ga_{.47}As$ quantum wells were grown between $In_{.52}Ga_{.24}Al_{.24}As$ barriers with a bandgap energy of 1.1 eV. The resulting structures show efficient photoluminescence around 1.3 µm. Characterization by TEM revealed abrupt interfaces.

Separate confinement heterostructure InGaAs/InGaAlAs multi-quantum well (SCH MQW) layer structures are being grown for active devices such as lasers and optical amplifiers.



Room-temperature photoluminescence spectra of bulk $In_{.52}Ga_{.24}Al_{.24}As$, bulk $In_{.53}Ga_{.47}As$, and a MQW structure based on $In_{.53}Ga_{.47}As$ wells and $In_{.52}Ga_{.24}Al_{.24}As$ barriers. Well and barrier thicknesses are 2.6 nm and 10 nm, respectively.

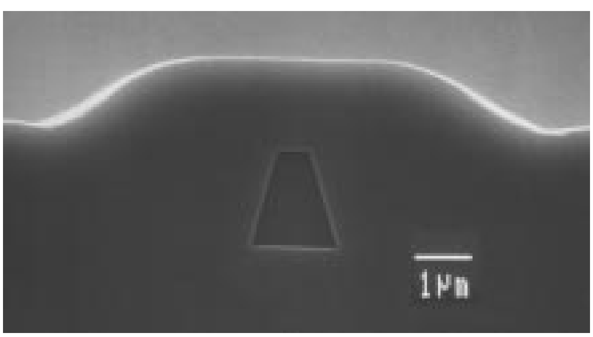
Buried Optical Waveguides in Indium Phosphide

M. Lanker, E. Gini

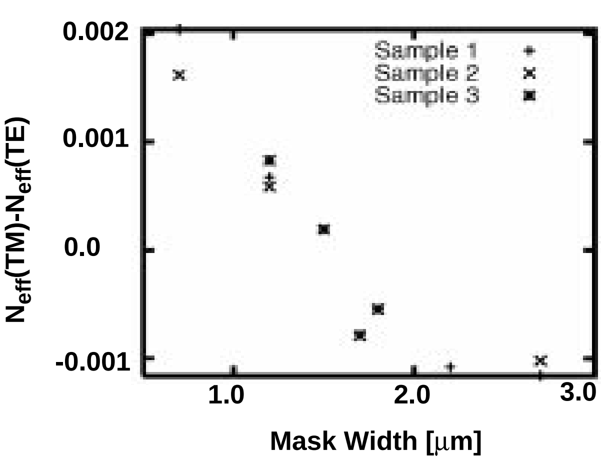
Most optoelectronic devices realized in our group are based on ridge waveguide structures. However, they show a polarization dependency not in losses but in effective refractive index. In order to realize polarization insensitive optical devices based on the concept of phased arrays, such as waveguide routers, wavelength demultiplexers, add-drop multiplexers, we need polarization insensitive optical single mode waveguides in both loss and effective refractive index.

In order to obtain the same effective refractive index for both TE and TM modes, we use an almost quadratic InGaAsP waveguide core embedded in InP. We have choosen a low index contrast between core and cladding, leading to a large mode size and thus low waveguide-to-fibre coupling losses. The fabrication of the waveguides is based on two MOVPE growth steps and dry etching. Waveguides with different widths and core compositions were realized. A SEM picture of an example is shown below.

Optical characterization of the waveguides at λ=1.55 μm show propagation losses of about 2 dB/cm. The difference in loss between the polarizations is below 0.3 dB/cm and the birefringence is less than 0.001 for a reasonable wide range of waveguide widths. Typical birefringence of our ridge waveguides is 0.003. The buried waveguides are being implemented in phased array devices.



SEM picture of a cleaved buried waveguide. The sample was stain etched to enhance the contrast between core and claddings



Measured birefringence of buried waveguides as a function of the mask width at λ=1.55 μm.

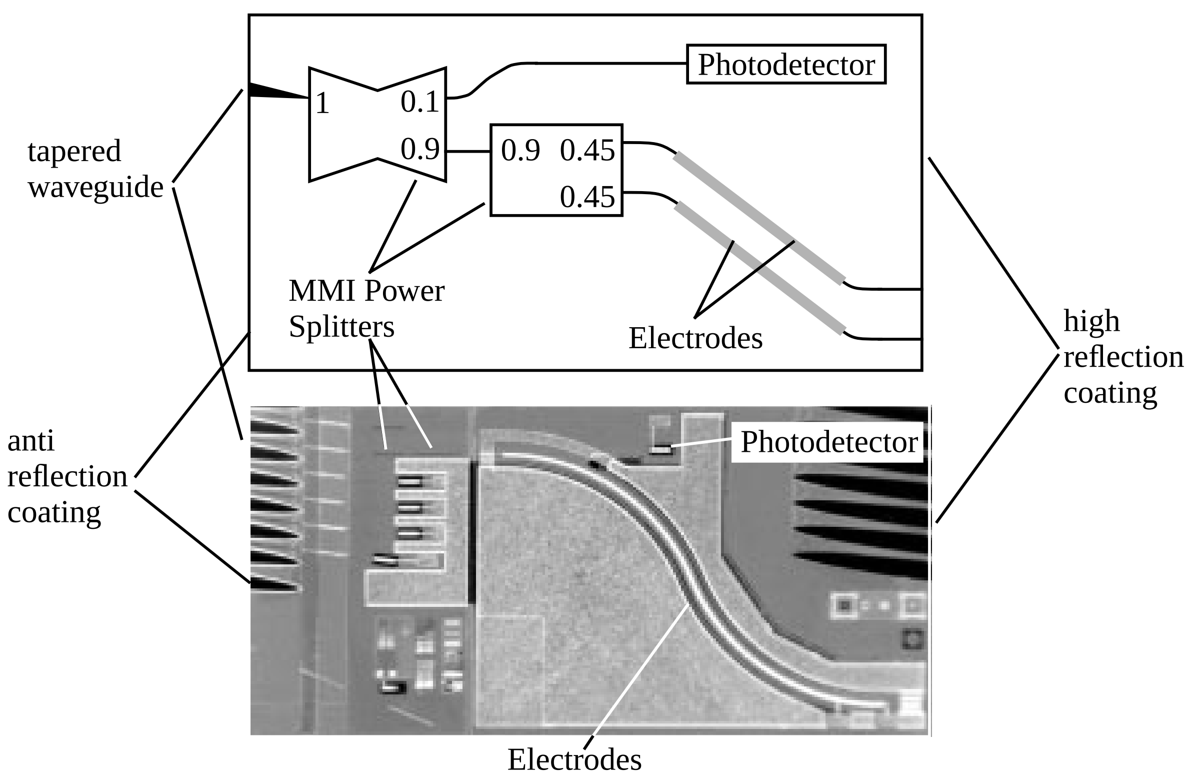
Optical Transceiver Featuring Monolithically Integrated InP / InGaAsP Photodetector and Reflective Modulator

G. Hagn

The growing demand for bandwidth of various telecommunication applications like internet, video on demand, telebanking, etc. optical transmission of data is becoming more and more important. To meet the goals of high performance and low cost, integration of optoelectronic components into single chip is necessary. Towards this end, we have developed a monolithic transceiver in InP that combines a photodetector for the incoming signal and a modulator for transmitting the outgoing signals for the use in passive optical networks.

The transceiver is integrated as an InGaAsP waveguide structure on InP substrates. From the incoming light 10% is split-off or detection an a waveguide p-i-n photodiode. The major part of the light is put into a Mach-Zehnder Interferometer type Reflection Modulator that imposes the information to be sent back. For efficient waveguide to fiber coupling the InGaAsP InP waveguides are tapered.

The reflection modulated transceiver operates polarization independent in the 1.3 micrometer range. In Reflection fiber to fiber losses are below 10dB. Modulation rates reach several hundred MB/s. Drive voltages are below 4 Volts. Detection responsivity is 50 mA/W. The modules are pigtailed and packaged using laser welding.

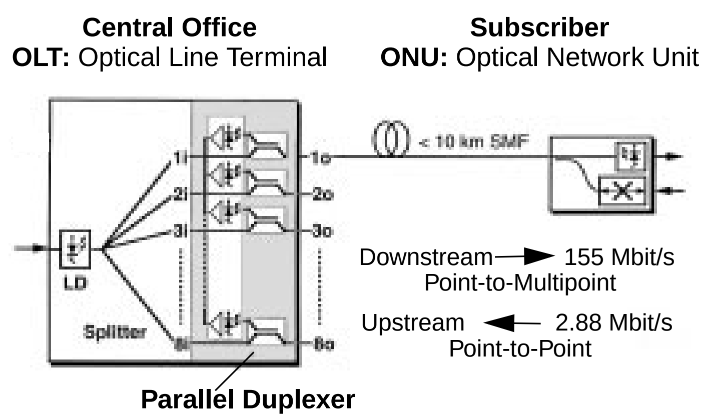


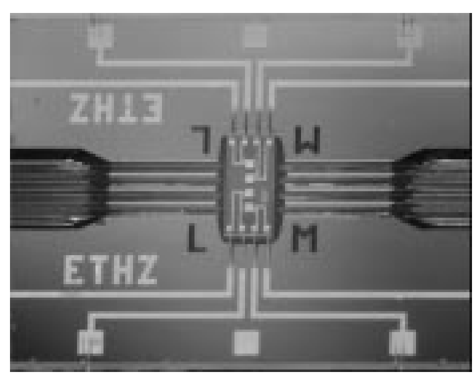
Schematic and photograph of a transceiver

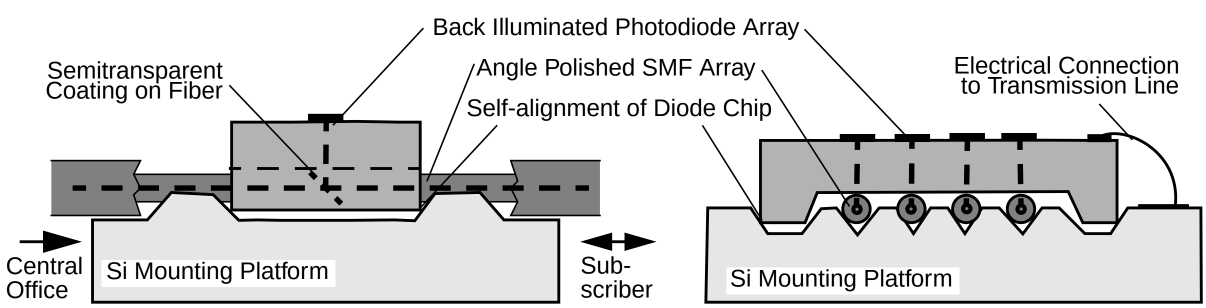
Multi-Channel Duplexer Module for Fiber in the Loop Application

W. Hunziker

This multi channel duplexer is an optical combining/splitting element with integrated photodiode in an array configuration for multiple subscriber applications. The Fiber in the loop (FITL) concept pursued at Ascom Tech provides a bidirectional service via one single mode fiber for both, downstream and upstream communication. Laser diodes at the central office distribute the information to several (4,8 or 12) subscribers and low cost reflective modulators are implemented at the subscriber side. Each channel has to be terminated at the central office with its own dedicated receiver (see system sketch on top left). A low cost parallel duplexer module for the central office has been developed, providing access to the back reflected light of the upstream channel. As packaging dominates the cost of optoelectronic modules, the realized device is based on only three components that are passive aligned on a silicon mounting board with alignment features (bottom figures). Two angle polished fiber ribbons, one coated with a beamsplitter thin film, are aligned in wet etched V-grooves realizing the transmission for the downstream channel. A photodiode array chip with backside processing fits into etched grooves on the same Si motherboard providing self-alignment with the beamsplitters for extraction and detection of the upstream information. The realized 4 channel modules (center part shown on top right) show low polarization sensitivities of <1dB, low beamsplitter and alignment losses of ~1dB, low crosstalks of <-35dB and good thermal stability in a -40˚C to +80˚C cycling test.



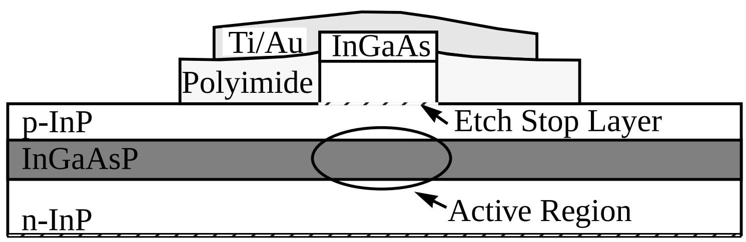




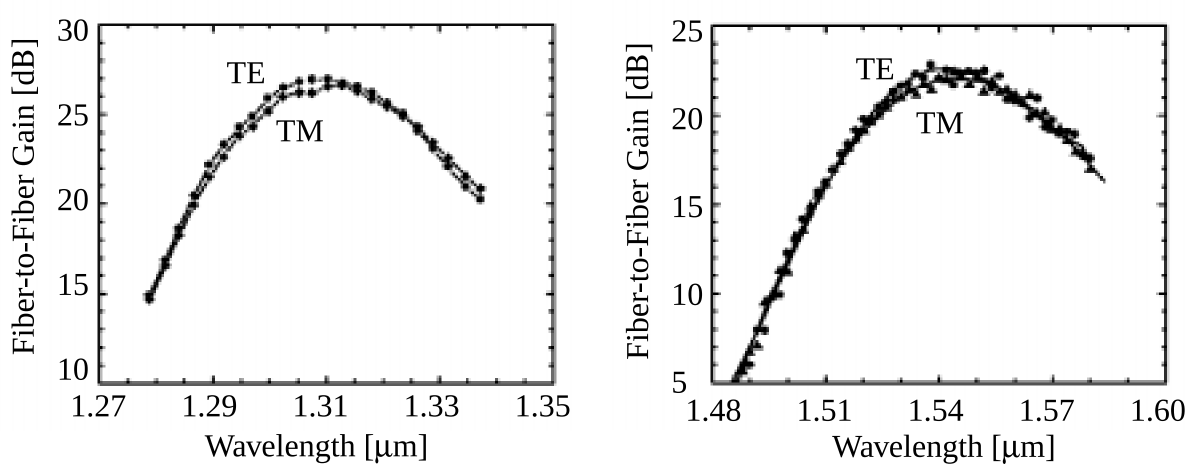
High Performance Polarization Independent Semiconductor Optical Amplifiers for 1.3µm and 1.55µm Wavelengths

Ch. Holtmann, J. Eckner, R. Dall'Ara and H. Melchior

Semiconductor optical amplifiers (SOA's) are attractive, both for the amplification and for the switching of optical signals in the 1.3µm and 1.55µm wavelength ranges of interest for fiber optical communication.
We have realized SOA's for both of these wavelength ranges. They are based on InGaAsP/InP epitaxial material technology. For polarization independence they exploit a bulk-active ridge-waveguide structure. Monolithically integrated with passive waveguides, they are useful as optical gate arrays.



Semiconductor optical amplifier grown in InGaAsP/InP with bulk-active ridge-waveguide structure, optimized for polarization independent operation.



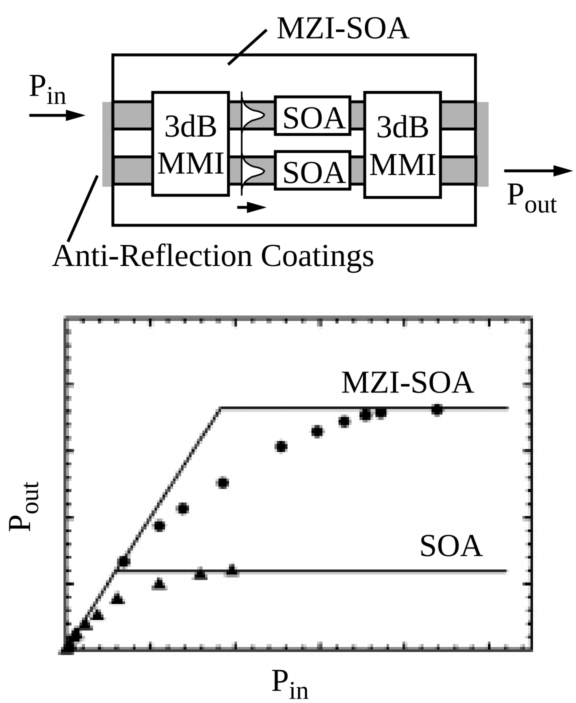
Fiber-to-fiber gain spectra of packaged SOA's operating at 1.3µm and 1.55µm wavelengths. Note equal gain spectra for TE and TM modes.

Semiconductor Optical Amplifier Arrays Coupled in Mach-Zehnder Configuration for Improved Output Powers

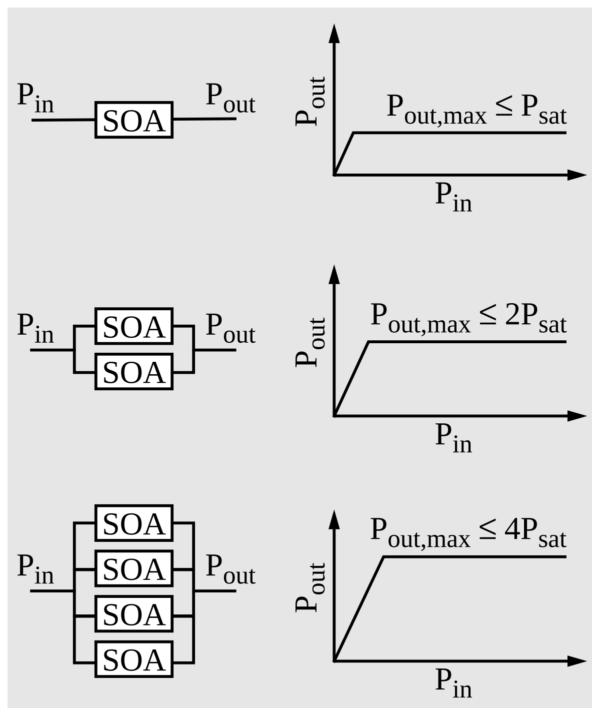
Ch. Holtmann, W. Vogt, E. Gamper, P. A. Besse and H. Melchior

High single-mode optical powers coupled into single-mode fibers are a key for many applications in meteorology, medical surgery, laser machining and optical communications.

To achieve this, we are investigating the coherent coupling of laser diode or semiconductor optical amplifier (SOA) arrays. In one such an arrangement semiconductor optical amplifiers are monolithically embedded into monolithic Mach-Zehnder interferometer structures and used for phase coherent amplification of light from a single longitudinal mode laser. The maximum output power from an MZI-SOA array with N SOA's is expected to reach N times the saturation power of a single SOA.



Conceptional view (top) of Mach-Zehnder interferometer (MZI) with SOA's in its arms for coherent coupling of amplified signals (MMI=Multi Mode Interference Coupler). Improved gain dynamic and output saturation powers are shown at bottom.



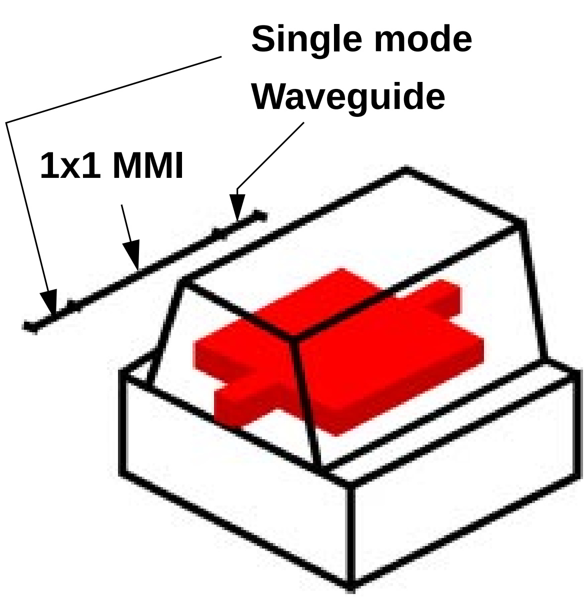
Concept of Mach-Zehnder interferometer coupled SOA arrays for improved overall SOA gain dynamics and saturation power.

Single Transverse Mode Active Multi-Mode Interferometer Laser Diode for High Power Applications

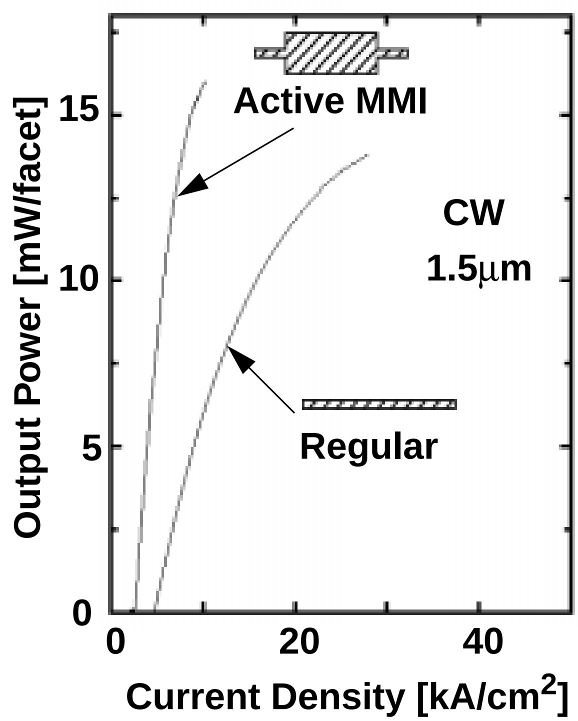
Kiichi Hamamoto, Emilio Gini, Christoph Holtmann, and Hans Melchior

High power laser diode (LD) is attractive for many applications, for instance, long distance telecommunication system, compact disk pick-up, and others. One of the way to obtain high power LD is to utilize multi mode waveguide structure since it provides wider pumping area than one of regular single mode LD. On the other hand, single transverse mode output, which is contrary to widening the pumping area, is one of the essential requirements for those above applications.

To realize single transverse mode LD by utilizing multi-mode waveguide, we invented an novel active multi-mode interferometer (active MMI) LD, which incorporates 1×1 MMI in between single mode waveguides. By exploiting it to regular infrared LDs, efficiency and single transverse output power have been increased significantly compared with regular LD. Moreover, significant threshold current density reduction has also been obtained. These results predict the drastic improvements in every LDs characteristics.



Schematic of active MMI LD



LD output power

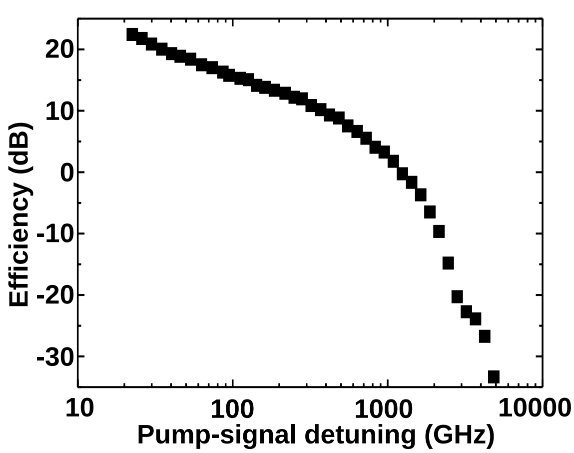
Highly Efficient Four-Wave Mixing in Bulk Semiconductor Optical Amplifiers

F. Girardin, J. Eckner and G. Guekos

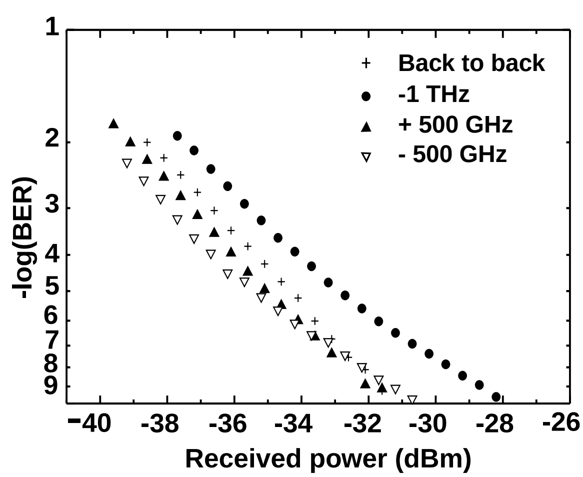
Future high bit-rate optical networks call for high-speed all-optical devices. The four-wave mixing (FWM) is a key contender for optical networking, since it has the unique feature of being compatible with wavelength division multiplexed data streams, with phase and frequency modulated signals, and with analog signals.

The FWM effect in semiconductor opitcal amplifiers (SOA) was however thought to be a rather unefficient process. In the frame of a collaboration with the Fondazione Ugo Bordoni, Rome, the increase of the length has been shown to lead to a higher efficiency, due to the increase of the unsaturated gain. It has also been shown that the limitation of the gain due to amplified spontaneous emission does not limit the FWM performance. Record efficiency of +5 dB at 1 THz pump-signal detuning together with a high signal to background ratio have been obtained in 1.5 and 2 mm long bulk SOAs.

The use of pigtailed devices in sub-system experiments has lead to a successful signal frequency conversion up to 2 THz at 2.5 Gbit/s. Improvements of the sub-system setup are in progress in order to measure the performance of the devices at higher bit-rate by using FWM and cross gain modulation schemes.



Four-wave mixing efficiency versus pump-signal frequency detuning in a 1.5 mm long SOA.

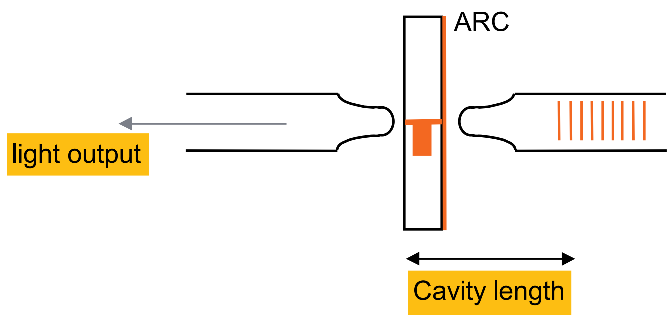


Bit Error Rate (BER) for the fre-quency conversion of a signal at 2.5 GBit/ with three different conversion spans.

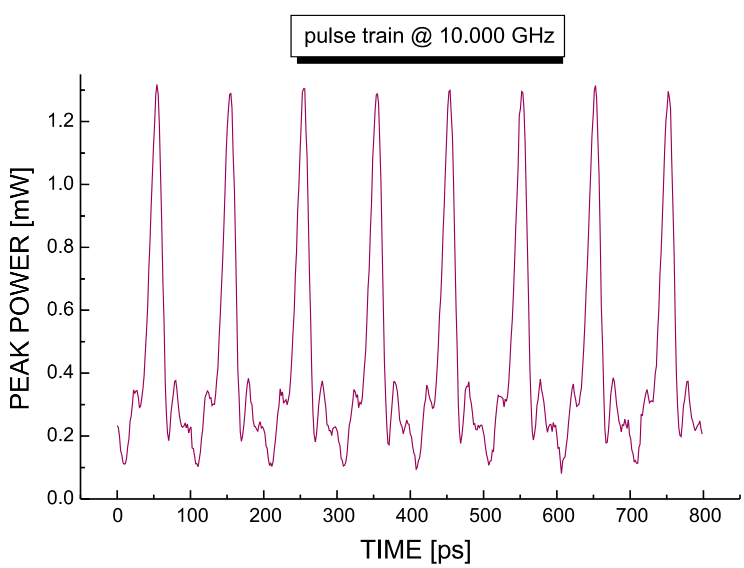
High Bit Rate Optical Pulse Sources

M. Dülk

Optical pulse sources are key components for optical networks, for instance as optical clock signals or for wavelength conversion or optical switching. The repetition or bit rates of these sources lie in the GHz regime (2.5 GHz, 10 GHz or more) and requested pulse durations are about 15 ps or less. For reasons of synchronization, the repetition rate of the pulse sources has to be actively controlled. The approach for realizing such a pulse source is the technique of active mode-locking or gain-switching in combination with linear pulse compression. Here, the gain, loss or phase is modulated with an RF frequency that is equal to the longitudinal mode spacing of the laser which, in turn, depends on the round-trip time of the travelling pulse. Laser chips are usually very short (150-500 µm), hence the round-trip frequency is very high (100-200 GHz). Thus, for active mode-locking the laser is extended, for instance by means of fibre Bragg gratings, to form an external cavity laser. Fibre Bragg external cavity lasers with a total length of about 10 mm have been realized to produce mode-locked laser pulses of 10 to 15 ps at repetition rates of 10 GHz.



Schematic set-up of a fibre Bragg external cavity laser: A laser is provided with an anti-reflection coating (ARC) on one facet for coupling to an external fibre Bragg grating (right side). Light output is detected at the other facet of the laser chip when using a high-reflecting fibre Bragg grating as shown here.



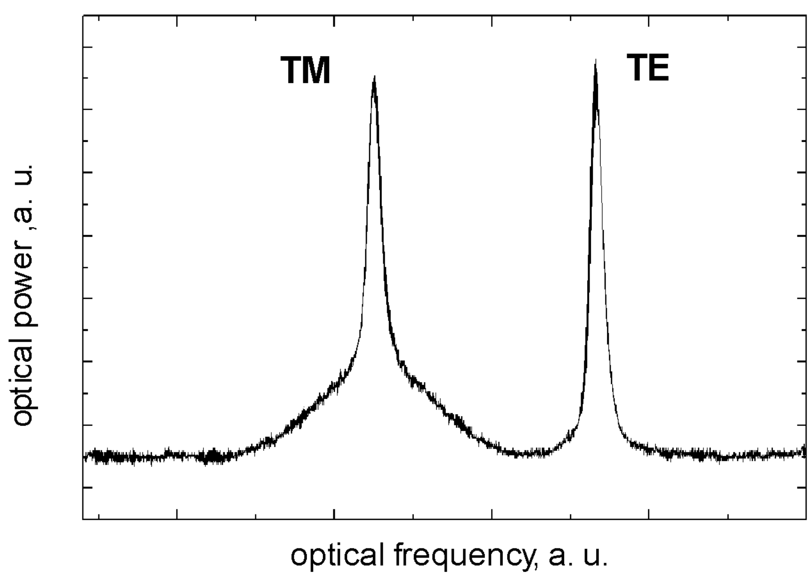
Train of mode-locked pulses of 15 ps at a repetition rate of 10.0 GHz, obtained with external cavity laser shown above.

Antenna Fiberoptic Remote Feeding Using a Dual-Polarization External Cavity Diode Laser

S. Pajarola, G. Guekos, H. Kawaguchi (Yamagata University, Japan)

The optical generation and distribution of millimeter-wave antenna signals to be employed in future broadband mobile communications networks has recently attracted much interest.

We have demonstrated a 1.55 μm dual-polarization emission external cavity laser (DP-ECDL) of which both, the TE and the TM mode can be tuned independently in wavelength over approximately 60 nm. In a fast photodetector, the beating of the two modes create the millimeter-wave of desired frequency according to the wavelength separation of the optical modes. We have shown the feasibility of data transmission using this technique by implementing the optical transmission part of a virtual down-link. For this, the output of the DP-ECDL coupled into a polarization maintaining fiber was split into the TE and the TM component, of which the latter passed a $LiNbO_3$ Mach-Zehnder interferometer modulator. The two optical portions were recombined in a fiber directional coupler and finally detected in a high-speed photodiode that generated the electrical millimeter-wave. This signal was subsequently down-converted, amplified, and demodulated using a self-multiplication scheme. In a first transmission experiment, the modulator was fed with a 140 Mbit/s binary amplitude shift keyed signal, and the mode separation was adjusted such as to produce a millimeter-wave carrier at 58 GHz.

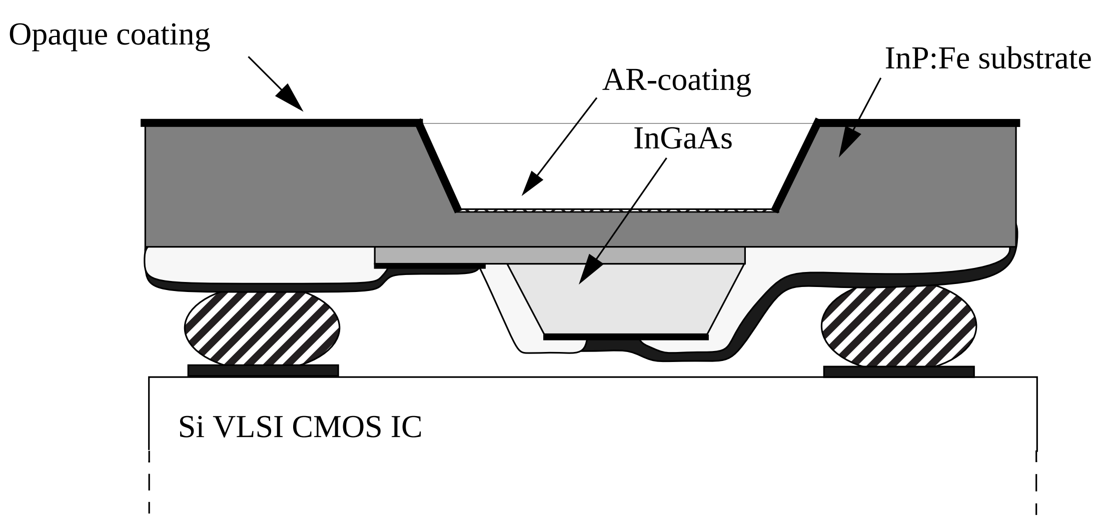


Fabry-Perot spectrum of the DP-ECDL under modulation of the TM mode. The modulation sidebands are apparent around the TM mode. The actual mode separation of 58 GHz cannot be deduced from the figure.

InGaAs/InP Photodiode Array for Optical Interconnect

M. Blaser

The target of this project is to develop a two-dimensional, back-illuminated InGaAs/InP photodiode array, that can be flip-chip mounted on silicon VLSI chips. Optical interconnects offer the possibility to remove the electronic interconnect bottleneck which arise from ever increasing IC complexity, speed and interconnect requirements. Two-dimensional flip-chip mounted InGaAs/InP photodiode arrays are key components for high-throughput optical intra- and inter-chip interconnects (as opposed to edge). In order to obtain an efficient, high speed optoelectronic interface between the silicon integrated VLSI electronics and optical fibres, an InGaAs/InP pin photodiode array is developed that is flip-chip mounted on the silicon IC and that allows simultaneous illumination with a wavelength of 980 nm through the substrate. A cross-section through the photodiode chip, illustrating its concept is shown in the figure below. The scalable photodiode array chip consists of 4 x 8 back-illuminated photodiodes with the active regions on a 250 x 250 grid. The light sensitive region is made accessible through a hole etched in the back-side of the wafer. The bottom of the hole is coated with an antireflection coating optimized for a wavelength of 980 nm, whereas the sidewalls are metallized in order to collect a maximum of the divergent light from the optical fibre and to minimize crosstalk due to light coupled to neighbour photodiodes in the array. In order to prepare the photodiode array chip for flip-chip solder bonding, the solder is deposited on the photodiode InP wafer.



Generic structure of a single InGaAs/InP photodiode for solder bump flip-chip mounting on the silicon VLSI CMOS chip

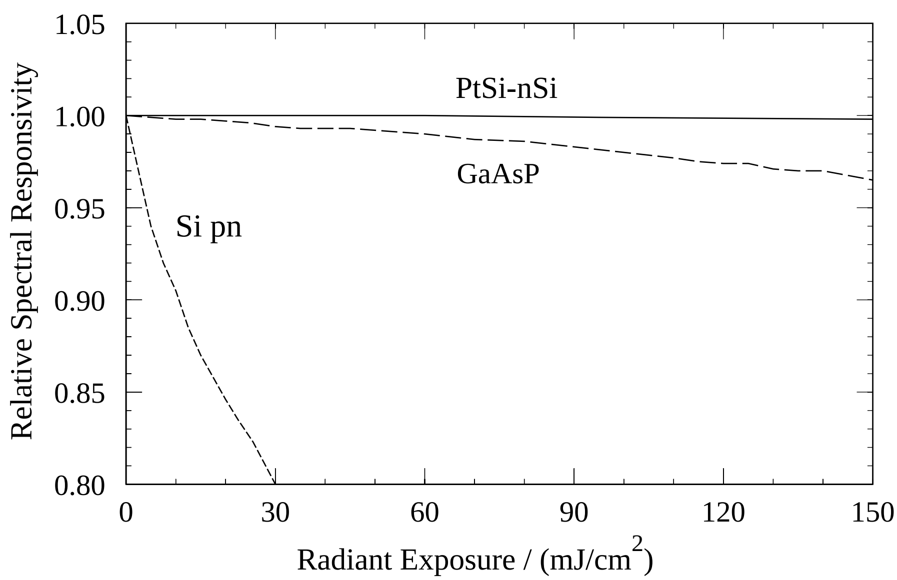
Fast Operating, Large Area PtSi-nSi VUV Photodetectors with Stable Spectral Responsivity in the 120 nm to 400 nm Wavelength Range

K. Solt, H. Melchior: Swiss Federal Institute of Technology, CH-8093 Zurich

M. Richter, U. Kroth, H. Rabus, G. Ulm: Physikalisch-Technische Bundesanstalt, Abbestrasse 2-12, D-10587 Berlin

P. Kuscherus, V. Persch: BESSY GmbH, Lentzeallee 100, D-14195 Berlin

Large area front-illuminated PtSi-nSi Schottky barrier photodiodes with 100 mm^2 photosensitive area have been developed for use as radiation standards in the ultraviolet (UV) and vacuum ultraviolet (VUV) spectral ranges. The photoresponse has a high stability under UV radiation, superior to those of the best VUV diodes, with a uniformity of <1% rms deviation over the active diode surface.



Relative spectral responsivity vs radiant exposure at wavelength 120 nm for Si pn and GaAsP Schottky (Hamamatsu S1337 and G2119) and PtSi-nSi Schottky (ETHZ) photodiode.

The diodes have a rise time <1 ns, as mesured at 820 nm wavelength with 100 fs laser pulses.

Low Power, Compact 2×2 Thermo-Optic Silica on Silicon Waveguide Switch with Fast Response

Q. Lai, W. Hunziker

For low speed applications as bypass or protection switches, thermo-optic silica on silicon waveguide switches are advantageous because of their low loss, polarization independence and long term stability. Besides the switching speed, the power consumption and needed space per switch are important parameters. We have realized a 2×2 thermo-optic silica on silicon waveguide switch that combines compactness, low polarization independent losses with low heating powers of 110mW for π phase shift and response speeds as fast as 150µs rise and 180µs fall times. A special waveguide structure, the diffused square waveguides shown in AA' cross section, allows deep etch trenches outside or between waveguides. This provides efficient heating of a small square dimension, fast heat removal and good thermal separation of closely spaced waveguides. The extinction ratio for both cross and bar output exceeds 21dB and the fiber-to-fiber insertion loss is about 1dB.

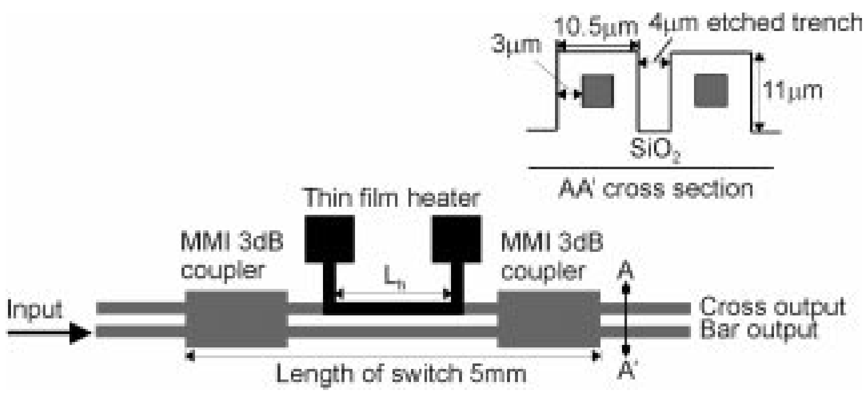


Fig. 1 2×2 thermo-optic switch based on silica on silicon Mach-Zehnder Interferometer. Insert shows profile of the waveguide structure in AA' cross section.

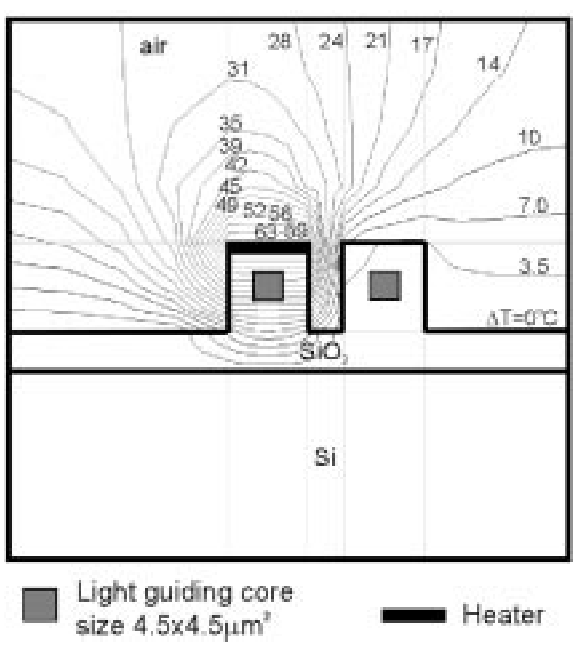


Fig. 2 Steady state thermal analysis of the waveguides in the MZI section showing temperature distribution for heating power of 110mW.

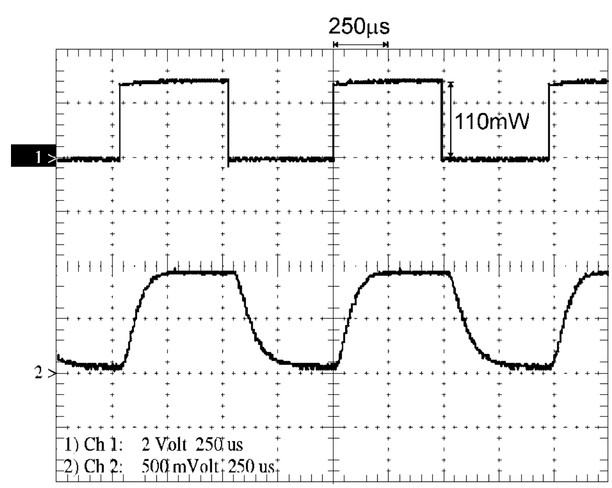


Fig. 3 The optical response (lower trace) of the thermo-optic switch to current switching (upper trace).

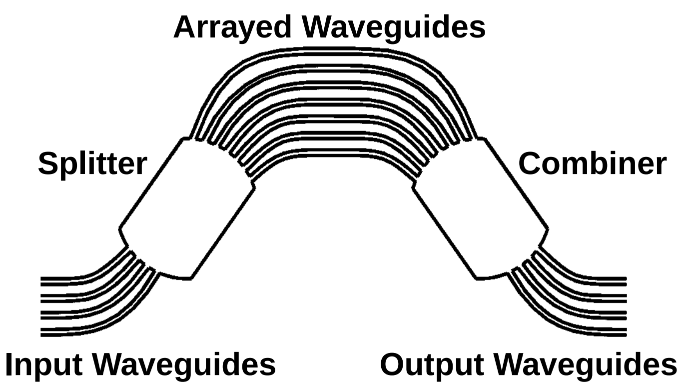
Wavelength Multiplexer/Demultiplexer Filters in Glass on Silicon

Ch. Nadler, M. Lanker, and E. Wildermuth

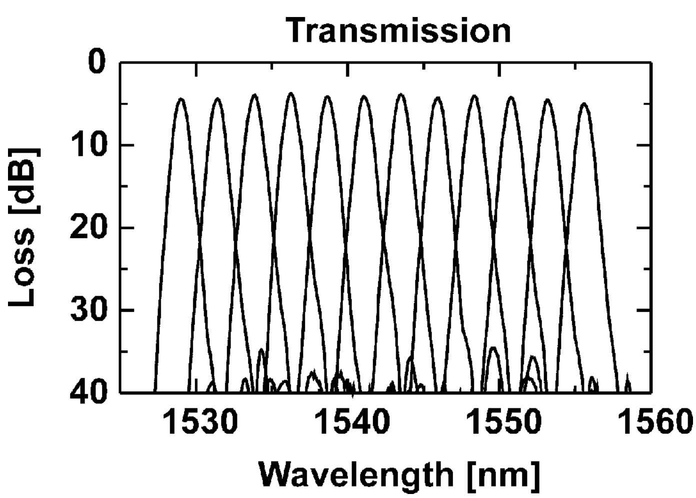
Wavelength division multiplexing (WDM) is becoming increasingly important in fiber optical communications, since it offers full exploitation of the almost unlimited bandwidths of optical fibers. Key elements of WDM are wavelength multiplexer/demultiplexer filters.

For an optical packet switching and routing network we used the arrayed waveguide grating (AWG) concept to realize wavelength filters.

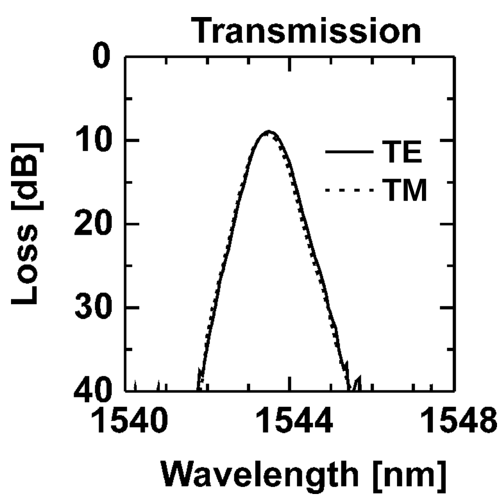
The silica on silicon technology is attractive because it offers low insertion loss, low crosstalk, good reproducibility, and long term stability. However it holds an undesirable polarization dependence owing to the strain birefringence. Using a stress releasing technique we reduced the polarization dependence of the filter significantly while maintaining the good filter performance in crosstalk and loss.



Schematic layout of a 4x4 wavelength division multiplexer using free space couplers as splitter and combiner.



Measured transmission curves of the twelve output waveguides of a 12x12 wavelength division multiplexer using free space couplers. A very good crosstalk below -30 dB and fiber-to-fiber loss below 5.3 dB has been obtained.



By applying a stress releasing technique we achieved a very low polarization shift < 0.05 nm.

Indium Phosphide Heterobipolar Transistor and Integrated Circuit Technology

R. Bauknecht

A high-performance indium phosphide (InP) heterobipolar transistor (HBT) technology has been developed for the realization of high-speed integrated circuits by design groups within and outside of our group. The HBT fabrication process on two-inch InP wafers is based on metal-organic vapor phase epitaxy (MOVPE) and self-aligned metallization deposition techniques. Key targets for this process were good reproducibility, high yield and high device reliability.

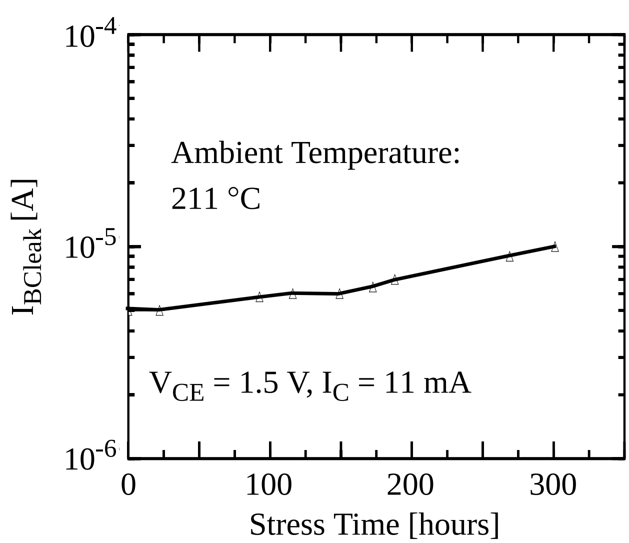
Two design options are employed: The single HBT (SHBT) technology with InGaAs collectors is optimized for ultimate high-speed performance, the double HBT (DHBT) technology with InP collectors combines high breakdown voltages, high maximum current densities and excellent high-frequency performance. Typical performance results of single transistors are shown in the table below.

The yield obtained for circuits with typically 30-50 transistors is very good, typically > 80%. Preliminary accelerated lifetime tests for DHBTs under bias stress conditions at collector current densities $J_C = 0.6 \cdot 10^5$ A/cm^2 and collector-emitter bias voltages $V_{CE} = 1.5$ V reveal lifetimes of > 300 hours at 235 °C junction temperature. This is comparable to data reported for state-of-the art InP HBT processes.

Applications of this InP HBT technology include integrated circuits for the use in fiber optical communications, such as fast multiplexers/demultiplexers, broadband amplifiers, driver circuits and monolithically integrated optical receivers as well as circuits for student projects such as voltage controlled oscillators.

	SHBT	DHBT	unit
β	27	22	
BV_{CEO}	6	13.5	V
f_T	70	80	GHz
f_{max}	150	126	GHz
P_{max}	1.0	2.5	mW/μm^2

Typical performance of InP HBTs. P_{max} is the maximum power dissipation per emitter area.

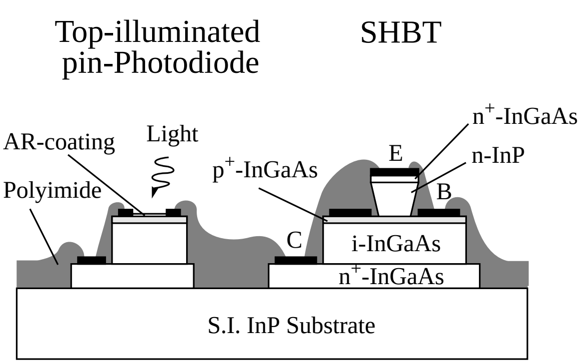


Base-collector leakage current of an HBT with 2.2x8 μm^2 emitter as function of stress time.

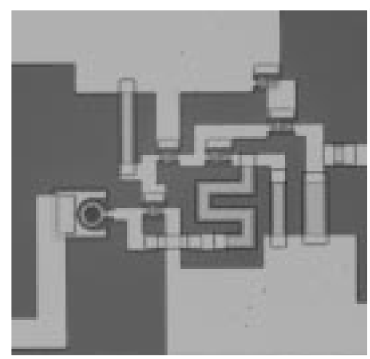
Integrated Photodetector-Heterobipolar Transistor Optical Receivers

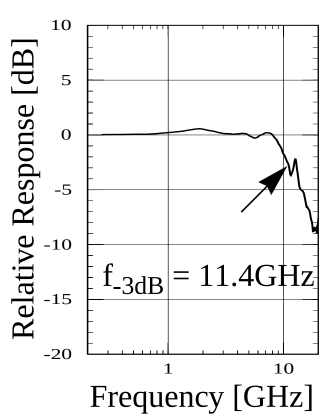
M. Bitter, R. Bauknecht

Increasing data rates of lightwave transmission systems demand for high-speed optical receivers with high sensitivity and good dynamic ranges. Based on our InP/InGaAs technology, we monolitically integrated pin photodiodes with single-heterobipolar transistors. The packaged monolithic pin photodetector-transimpedance amplifiers designed for 10 and 20Gb/s operation at 1.55μm wavelengths show sensitivities of -19.7dBm and -15dBm, respectively. Their dynamic range exceeds 15dB. Equivalent input noise current density is as low as 6.5pA/√Hz. Together with the very low power consumption of only 36mW of the receiver chips this InP/InGaAs pin/SHBT technology demonstrates its suitability for high-speed, low-noise monolithically integrated optical receivers.

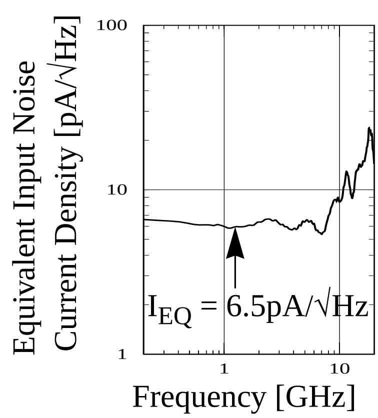


Optical receiver combining top-illuminated pin photodiode with single hetero-junction bipolar transistor amplifier. Cross-section view (left), chip photo (right).

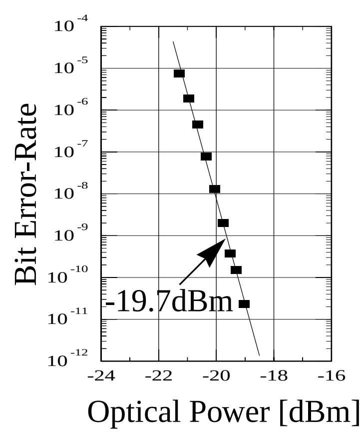




Frequency response of optical receiver. Bandwidth of 11.4GHz. Transimpedance gain of 420Ω.



Equivalent input noise current density.



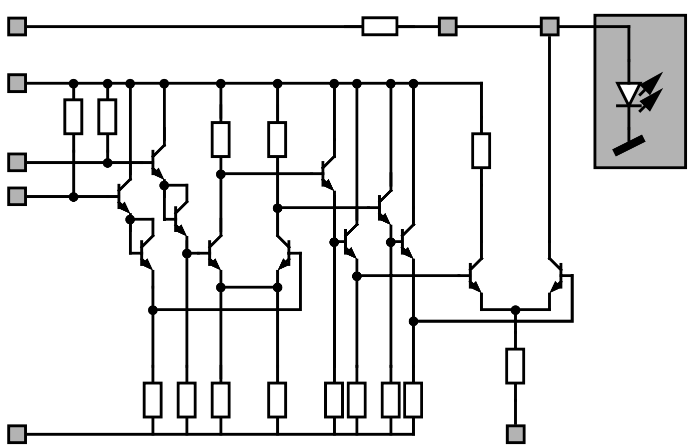
Bit error-rate at 10Gb/s with 2^{31}-1 PRBS NRZ signal coding. Sensitivity -19.7dBm at bit error-rate of 10^{-9}.

High-Speed, High-Current Electronic Drivers for Laser Diodes and Optical Amplifiers

H. Schneibel, R. Bauknecht

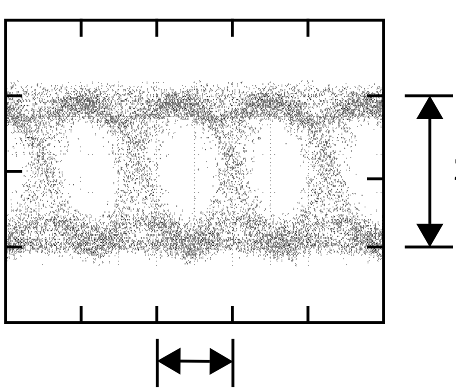
Fast driver circuits with high output currents for low impedance photonic devices such as lasers and semiconductor optical amplifiers (SOA's) have been realized. Drivers capable of driving 5 Ohm to 13 Ohm loads with up to 240 mA at 8 Gbit/s were achieved. The current into the loads is adjustable in the range from 20 mA to 240 mA. Rise and fall times are below 70 ps for all operating conditions. These drivers have been realized as well in twin-channel versions for operating laser and SOA arrays. If both channels are used simultaneously for one laser or SOA, modulation currents exceeding 400 mA are achieved. Successful operation of these drivers with gain-clamped SOA's, which require the maximum modulation currents, was demonstrated.

Two differential current switches build the basis of the internal circuit, which is shown schematically in the figure below. In the first stage the input signal is formed and re-levelled. The load is driven by an open collector output. The bias-current is supplied either through an on-chip resistor or an external resistor. The circuit, which has a power consumption of about 2.5 W, must be soldered on a copper heat sink for adequate cooling.



Laser Diode or SOA

Circuit Schematics



InP DHBT driver output signal across 8.3 Ω at 8 Gbit/s. Eye-diagram with horizontal 100 ps/div and vertical 120 mA/div scales.

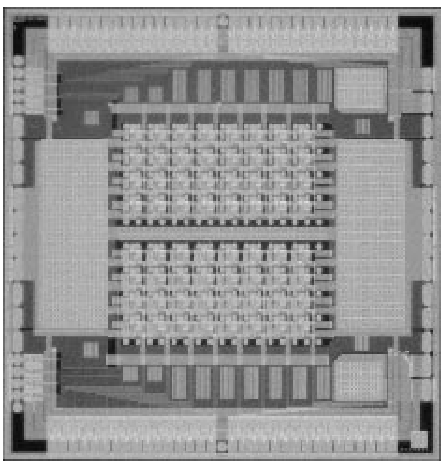
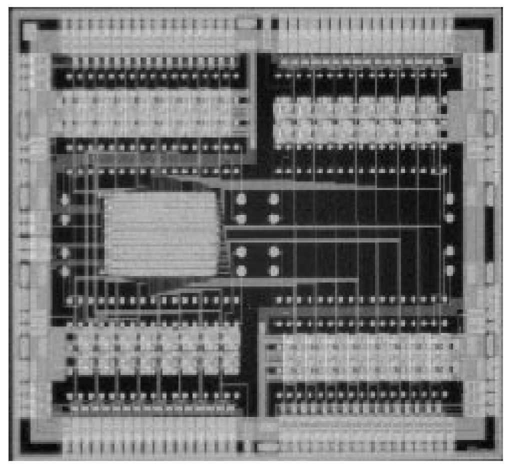
Silicon Integrated Circuits for Optical Interconnects

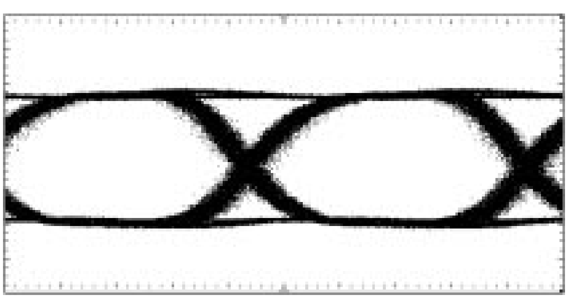
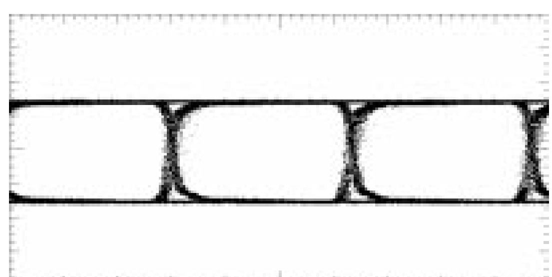
A. Schmid, M. Blaser, J. Wieland

In the near future the data throughput of inter- and intra chip communication will exceed the capabilities of standard electrical interconnections.

This project will establish key technologies and define relevant processing architectures allowing the introduction of high density two dimensional interconnections with aggregate capacities in the Gbit/s range.

We have designed a set of CMOS driver and receiver arrays for bitrates up to 600Mbit/s respectively 150Mbit/s per channel. The arrays are of 2*8 and 8*8 driver/receiver elements. The pitch of the single interconnection channels in 250µm in each direction. A photodetector array with 4*8 photo detectors has been designed and fabricated. The detector array will be flip chip mounted on the silicon receiver ICs.

	
8*8 Silicon Receiver Array	Demonstrator with 2*8 Elelment Driver and Receiver Arrays with Digital Logic

	
RX: 100 Mb/s, I_{PD}=20 µApp V_{SUPPLY}=3.3 V, PRBS=2^{15}-1 500mV/Div, 2ns/Div	TX: 600 Mb/s, I_{MOD}=1.4mA, I_{BIAS}=3.4mA, V_{SUPPLY},=3.3 V, PRBS=2^{31}-1 0.5ns/Div

CMOS Driver and Receiver Circuits for Optical Interconnects with Surface Emitting Lasers

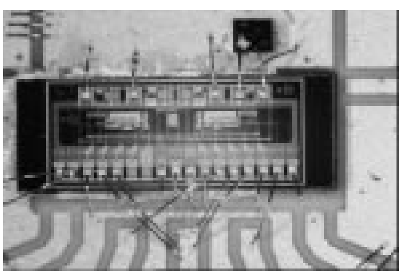
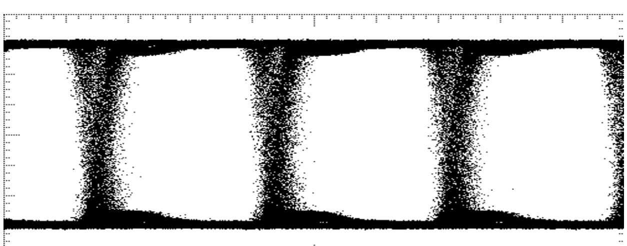
Patrick Zenklusen, André Schmid, Jörg Wieland

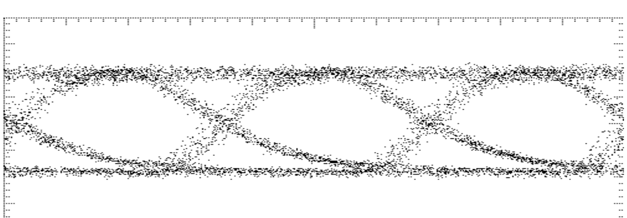
Optical interconnects combining parallel optical paths consisting of transmitter-, optical fiber or waveguide- and receiver-arrays are of interest for high throughput interconnections between electronic systems.

For such interconnects, that use vertical cavity surface emitting laser diode- (VCSEL-) arrays, we are developing electronic drivers and receiver circuits.

We designed a set of driver and receiver demonstrator chips, which allow to compare the propagation delay and the power dissipation of optical and electrical links. The driver works from DC up to 800Mbit/s. In this driver either the on chip voltage controlled oscillator (VCO) or an external applied signal can be selected as input signal. This input signal can be directed either to the optical or the equivalent electrical output. The receiver works up to 300Mbit/s. An on chip phase measurement circuit allows to measure the phase difference between the optical and the equivalent electrical link.

The integrated circuits have been fabricated on a commercial 0.8µm CMOS technology. The supply voltage for both circuits is 3.3V. Special care has been taken in the design to minimize the power dissipation.

	Measurement setup with demonstrator chip containing two independent VCSEL drivers and equivalent electrical output buffers in 0.8µm CMOS. Both electrical and optical output signals are generated either from the on chip VCO or from an external applied input signal.
	Eye-diagram of transmitter demonstrator at 700 Mbit/s; Supply voltage 3.3V; I_{Bias} = 2.5mA; I_{Mod} = 4mA PRBS = 2^{15}-1; Scale: 0.5ns/div; 50mV/div

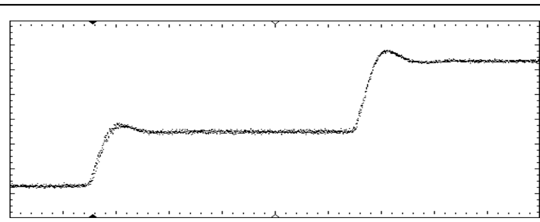
	Eye-diagram of receiver setup at 300 Mbit/s; Supply voltage 3.3V; I(Detector) = 15µA_{pp}; PRBS=2^7-1; Scale: 1ns/div; 100mV/div

Clock and Data Recovery Circuits for Fiber Optical Communication Networks

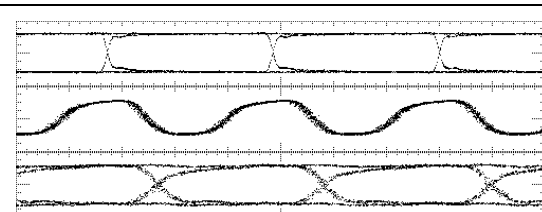
P. Nizzola

High performance fiber optical communication networks will take advantage of new and evolving technologies and switching/multiplexing/routing techniques, in particular ATM, SDH and IP (Internet Protocol). The clear channel approach, which allows the utilisation of the same physical link for different bit rates, protocols and network extensions, is at the moment one of the most promising solution that ensures the optimal exploitation of physical channels within networks. One of the key elements of such a network is the Clock and Data Recovery (CDR) circuit. The issues related with the CDR design are the wide bit rate range and the data format independence. Classical circuits based on the phase locked loops (PLL) or delay locked loops (DLL) structures have performances incompatible with the clear channel approach. On one side, the PLLs work with different protocols but only within a restricted bit rate range, while on the other side DLLs allow a wide bit rate range operation at cost of the protocol independence.

A modification of the CDR based on the PLL structure has fed to the implementation of a first prototype suitable for clear channel links. The circuit, realised in a commercial 0.8µm silicon BiCMOS technology, works at the bit rates of 622Mbit/s, 737Mbit/s and 1.06Gbit/s requiring only a small preamble to synchronise the incoming data. The requested power supply ranges from 3V to 5.5V at the low power dissipation of 100mW resp. 190mW. The output jitter is lower than 20ps at 622Mbit/s with PRBS 2^{31}-1 random sequence, decreasing further at higher bit rates. The following figures show measurement with a PRBS 2^{31}-1 random input data sequence at 3.3V power supply: left the CDR loop filter step response when changing the data bit rate from 600 to 700 and to 800Mbit/s, some eye diagrams at 1062Mbit/s and the output clock jitter at 1062Mbit/s.



PLL loop filter voltage showing the circuit step response with small overshoots. The picture has been taken while switching the three different data bit rates 600, 700 and 800Mbit/s. The three voltage levels shown above correspond to these three bit rates.
(20ms Horizontal.; 200mV Vertical)



Eye diagram at 1062Mbit/s with a PRBS 2^{31}-1 input. The top trace shows the input data, the middle trace the extracted clock signal and the bottom trace displays the extracted data.
(3ns Horizontal.; 400mV Vertical)

Infrared Sensor Arrays in Epitaxial Narrow gap Lead Chalcogenide Layers on Si- Substrates

H. Zogg, J. John, P. Müller, C. Paglino, K. Alchalabi, Y. Athanassov

Narrow band gap lead-chalcogenides are of use for fabrication of infrared detectors for the thermal wavelength (3-12 m)range. Layers such as PbSnSe and PbTe with band gaps of 0.1- 0.2 eV are grown by Molecular Beam Epitaxy (MBE). An intermediate CaF_2 buffer layer serves for compatibility. The quality of infrared devices critically depends on the quality of the layers. Contrary to narrow gap HgCdTe, dislocations in IV-VI layers can move easily along their main glide system at high and even at low temperatures. This behaviour can be used to improve the structural quality of the layers. Fig. 1 shows how dislocations moved towards the edges of a sample. The movement is caused by the thermal mismatch strain induced on temperature changes. Dislocation densities as low as 1×10^6 cm^{-2} and below were obtained after such anneals, and even on samples of several cm size. Keeping in mind that these values are obtained in 3 mlayers on heavily lattice mismatched substrates, these values compare favourably to HgCdTe layers on lattice matched CdZnTe substrates where dislocation densities of 10^5 cm^{-2} are observed. The layers are used to fabricate photovoltaic infrared sensor arrays for thermal imaging and spectroscopic applications. Fig. 2 shows the resistance-area product (essentially the inverse of the noise current density) as a function of temperature. The theoretical values as predicted by the Schottky-theory are obeyed down to about 100 K. Below this temperature, the change in slope is due to inhomogeneities of the Schottky barrier height.

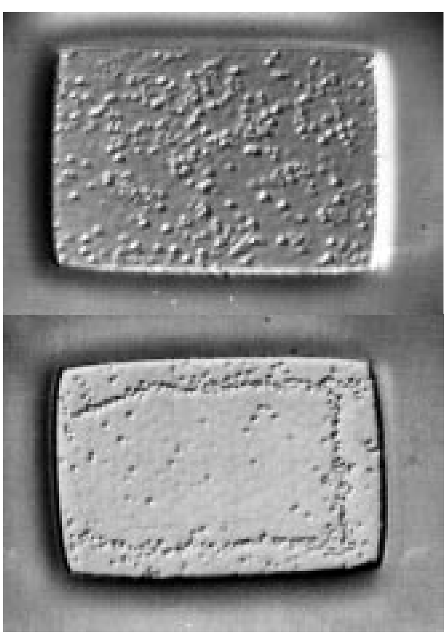
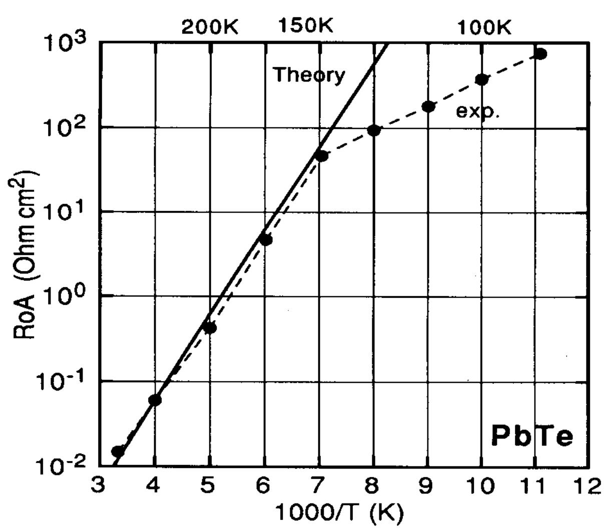


Fig. 1 (left). Dislocation (etch pit) density in structured PbSe layers on Si(111) before (top) and after (bottom) a thermal anneal at 300˚C.

Fig. 2 (bottom). Resistance-Area product RoA of a PbTe Schottky barrier infrared photodiode (5.5 m cut-off wavelength at 77K) as a function of temperature T



Sponsors: Swiss NF, GRD, KTI

Monolithic Two-Dimensional PbTe Infrared Sensor Array on a Read-Out Si-Chip

J. John, C. Paglino, K. Alchalabi, Y. Athanassov, H. Zogg

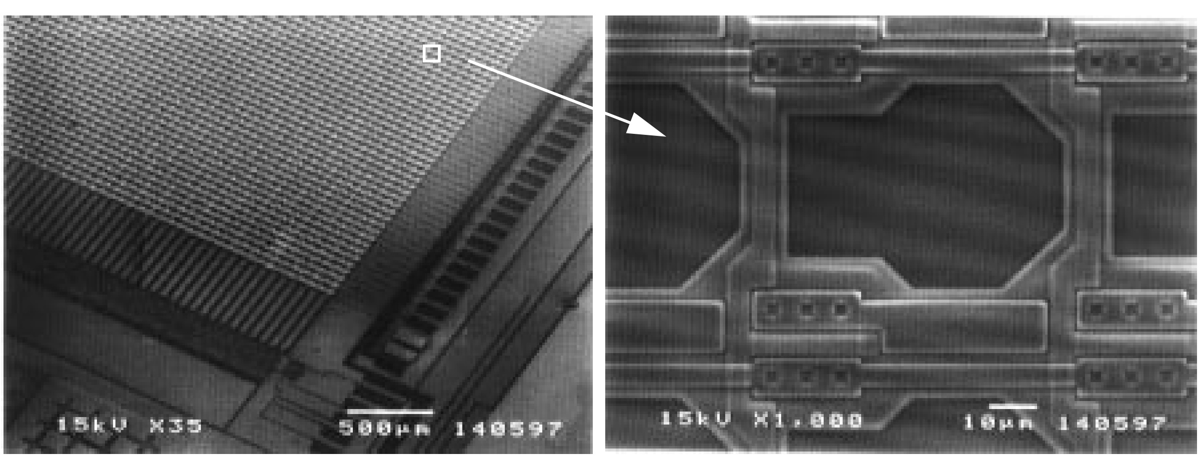
Infrared focal plane arrays for thermal imaging with the highest sensitivity use semiconductor infrared sensor pixels and are presently fabricated in a hybrid manner: The chip containing the 2-d array is fabricated in a suitable narrow gap material (or a III-V superlattice structure), while the read-out multiplexer is constructed with Si technology. Hybrid connections are usually formed by Indium bumps for each individual pixel. This makes the technique rather expensive for sensor arrays containing thousands of pixels.

Due to the easy molecular beam epitaxy of narrow gap PbTe and $Pb_{1-x}Sn_xSe$ layers on Si(111)- substrates, a monolithic design becomes possible by growing the infrared sensor material as a thin layer directly onto the Si read-out chip. A linear PbSnSe-on-Si photovoltaic infrared sensor array has already been realized. In the present project, a 2-d array is fabricated for the first time on an active Si-substrate. The read-out chip is designed in CMOS technology on double side polished Si(111). It contains a switching transistor for each individual pixel, and a shift register to access the lines serially. The columns are fed out in parallel to an amplifier chip. The array contains 128 x 96 pixels on a 75 mpitch. The design and fabrication was done by W. Buttler, Essen, and Fraunhofer-Institut Duisburg, respectively.

Presently, we have demonstrated the epitaxial growth of the material in the 50 mlarge openings of each pixel dedicated for the infrared sensors. A special low temperature cleaning technique had to be developed to this end in order not to destroy the chip structure including the Al-interconnections. The maximum temperature budget used was about 450˚C for 30 min (for wafer cleaning and growth of the CaF_2 buffer layer), followed by about 3 h at 400˚C for the growth of PbTe. The individual further delineating steps are all developed, and fabrication is in progress.

Sponsor: GRD

Fig.: Part of the 2-d array showing the sensor arrays matrix and some individual pixels



Packaging of Thermoelectrically Cooled Infrared Sensor Array

H. Zogg, J. John, C. Paglino, K. Alchalabi, Y. Athanassov

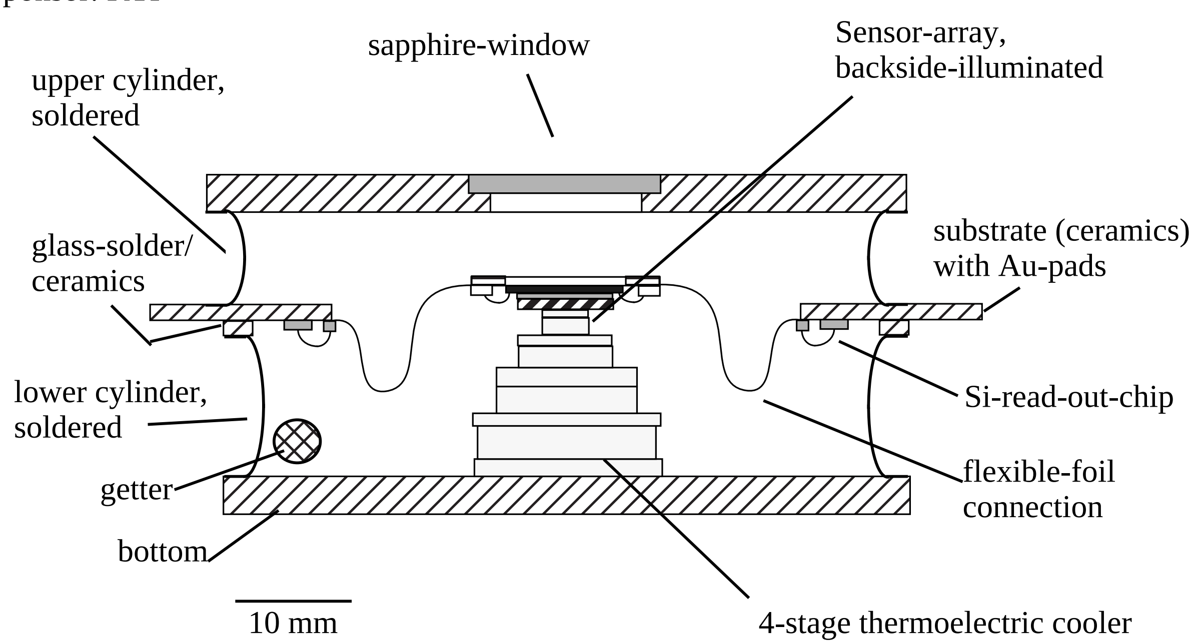
While sensitive semiconductor infrared sensor arrays for the atmospheric 8-12 m window have to be cooled to below 130K, thermoelctric cooling can be employed for certain applications for sensors operating in the 3-5 mwavelength range. A compact, completely sealed package is designed, the two industrial collaborations are funded within KTI projects. The sensor arrays (linear arrays with 128 elements, or 2-d arrays with 128 x 96 elements) are soldered on 4-stage thermoelectric coolers. Two amplifier chips each with 64 channels are bonded on a ceramic substrate and operate at room temperature inside the evacuated package. The electrical connections with the cooled sensor chip are done with a novel low thermal conductivity flexible kapton foil coated with thin film Au stripes.

The vacuum feedtroughs are constructed again with a novel thin film technique. The Au-pads on the ceramic substrate crossing the encapsulation are covered with a second ceramic ring and soldered using a special glass solder. The rest of the package as well as the sapphire window are again soldered, brazed or welded.

The Fig. shows a cross section of the encapsulation. A nonevaporable getter tube is built in since the maximum outgassing temperature is below 170˚C, therefore, reconditioning of the vacuum is possible.

The soldering techniques are developed in collaboration with B. Zigerlig, GVE-EMPA group at Technopark.

Sponsor: KTI



Growth and properties of epitaxial $CuIn_ySe_y$ layers and interfaces

A.N. Tiwari, M. Krejci, F.-J. Haug, H. Zogg

Copper indium selenide ($CuInSe_2$) and its alloys have emerged as the most important materials for stable and high efficiency polycrystalline thin film solar cells. Growth and characterization of epitaxial layers is important because bulk single crystals of these compounds are not easily available. Heteroepitaxial layers of single phase chalcopyrite ($CuInSe_2$) and defect-chalcopyrite (In rich $CuIn_xSe_y$ compositions) compounds were grown on Si and GaAs substrates by molecular beam epitaxy. Despite of a large lattice and thermal expansion mismatch, epitaxial layers of good structural quality have been obtained. Different phases have been identified and their structural and optoelectronic properties were investigated. Reactions (diffusion) and formation of microstructural defects at the substrate-layer interface have been investigated with Rutherford backscattering spectroscopy (RBS) and high resolution TEM. A high resolution TEM image of a $CuIn_xSe_y$/GaAs interface is shown in figure 1. The interfaces (on Si and GaAs) are not abrupt and defective regions in the range of 2 to 4 nm are observed along with a few stacking faults. In the case of $CuIn_xSe_y$ on Si, RBS measurements indicate the diffusion of Cu in to Si and the formation of an interfacial $CuSi_xSe_y$ layer. Figure 2 shows the RBS spectra of a (112) oriented epitaxial $CuIn_{2.5}Se_4$ layer. The absolute stoichiometry of different phases is determined with RBS and the crystal quality is evaluated by measuring the ion channeling minimum yield $\chi_{min.}$ (defined as the ratio of the yield in the aligned to a random direction). The $\chi_{min.}$ value of $CuIn_{2.5}Se_4$ layer is 7% which compares well with the 5% value reported for $CuInSe_2$ bulk single crystals. The x-ray diffraction rocking curve half widths are in the range of 700 to 900 arcs.

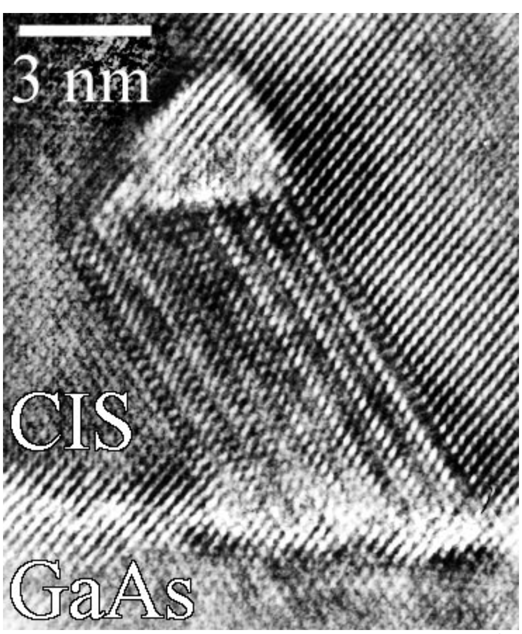


Fig. 1: TEM cross-section image of a $CuInSe_2$ layer with GaAs interface

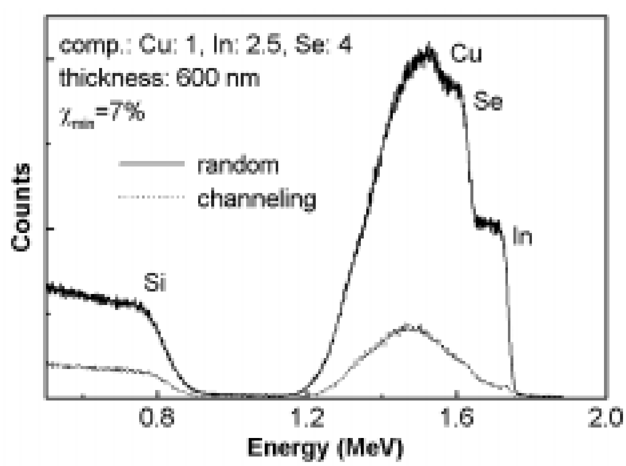


Fig. 2: RBS spectra of epitaxial $CuIn_{2.5}Se_4$ on Si(111)

Sponsor: PSEL, Swiss NF, BBW/BEW

Wide gap chalcopyrites for advanced photovoltaic devices

A.N. Tiwari, F.-J. Haug, M. Krejci, H. Zogg

The efficiency of a $CuInSe_2$ (band gap ~1 eV) solar cell is enhanced when Ga is added to increase the band gap of the absorber layer. The optoelectronic properties of $CuGaSe_2$ (band gap ~1.7 eV) are suitable to develop advanced photovoltaic devices with increased efficiencies. This project started in May 1997 and we are working for the following objectives: (i) to grow and characterize single phase epitaxial $CuGa_xSe_y$ layers of different stoichiometry, (ii) to develop the technologies for making composition graded and tandem solar cells of polycrystalline $Cu(In,Ga)_xSe_y$ layers. Experiments were performed to optimize the MBE conditions for the growth of crack-free heteroepitaxial $CuGa_xSe_y$ layers on (111) and (100) oriented Si substrates of 3 inch diameter. The RHEED patterns suggest that the layer starts to grow as islands (3-D growth) and the twining, formation of micro-cracks and impurity phases depend on the substrate temperature and evaporation fluxes. As shown in figure 1, sharp and well resolved electron channeling patterns with three-fold symmetry (characteristic of untwinned (111) or (112) growth) are observed for epitaxial $CuGa_xSe_y$ layers on Si(111) substrates. RBS ion channeling is used to evaluate the crystal quality. The RBS ion channeling minimum yield of ~28% for 0.6 μm indicates that the layer is epitaxial but further optimization of the deposition process is necessary to improve the crystal quality. Figure 2 shows the Raman spectrum of a (112) oriented heteroepitaxial $CuGa_xSe_y$ layer. The most intense peak at 184 cm^{-1} is due to the A_1 vibrational mode (Se bonded to Ga and Cu) in the chalcopyrite structure. The low intensity peaks are attributed to the TO and LO phonon modes (E and B_2 type) of the Ga-Se bond.

Polycrystalline $Cu(In,Ga)Se_2$ solar cells with an efficiency of about 13.3% (V_{oc} = 626 mV, I_{sc} = 29.1 $mA.cm^{-2}$, FF = 0.73) have been fabricated.

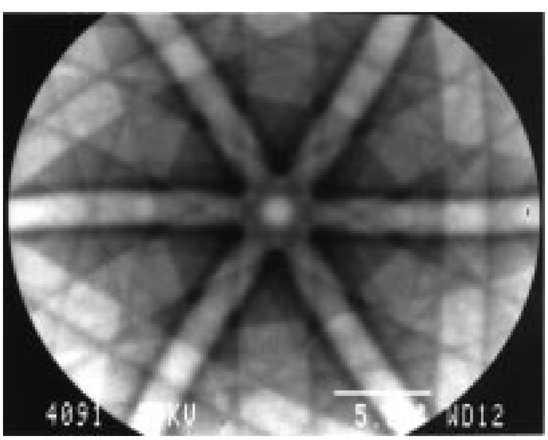


Fig. 1: Electron channeling pattern of $CuGa_xSe_y$ /Si(111).

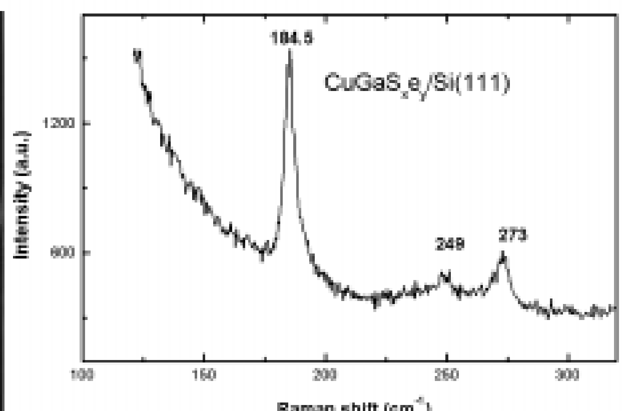


Fig. 2: Raman spectrum of 112 pattern of (112) oriented epitaxial $CuGa_xSe_y$ /Si(111)

Sponsor: BBW/EU (JOULE program)

CdTe/CdS thin film solar cells

A.N. Tiwari, M. Krejci, F.-J. Haug, A. Romeo, H. Zogg

CdTe/CdS solar cells are important for terrestrial applications. These solar cells do not pose any environmental or health hazard (CdTe and CdS are stable compounds). We have developed a process for making polycrystalline CdTe/CdS solar cells. This process in which all the layers (CdTe, CdS, $CdCl_2$, and ohmic back contact) are grown by vacuum evaporation has a potential for in-line industrial production of solar cells/modules. Polycrystalline CdTe/CdS stacks of good microstructure (oriented and compact grains) and optical characteristics are grown on ITO/glass substrates. Solar cells with a conversion efficiency of 10.7% (V_{oc} =800 mV, I_{sc} =21.7 mA.cm^{-2}, FF =0.62) have been obtained using a 0.4 µm thick CdS window layer. For a "specific application" we are working (since June 97) on the deposition and characterization of screen printed metallic grids on FTO/glass substrates. It was observed with SEM that the Ag lines of small widths (<50 µm) are discontinuous on the microscopic scale (see Fig 1a). These metal lines are composed of inhomogeneous islands (few tens of microns) separated by 1 to 5 µm regions of no-deposition over the FTO/glass (see Fig 1b). Despite this, the lines are electrically continuous but their resistivity (sheet resistance) is higher than that of the broader lines. Screen- printed Ag lines with widths >100 µm are uniform, dense, and suitable for the applications. The electrical resistivity is in the range of 2 to 6 µΩcm for lines of 50-100 µm width.

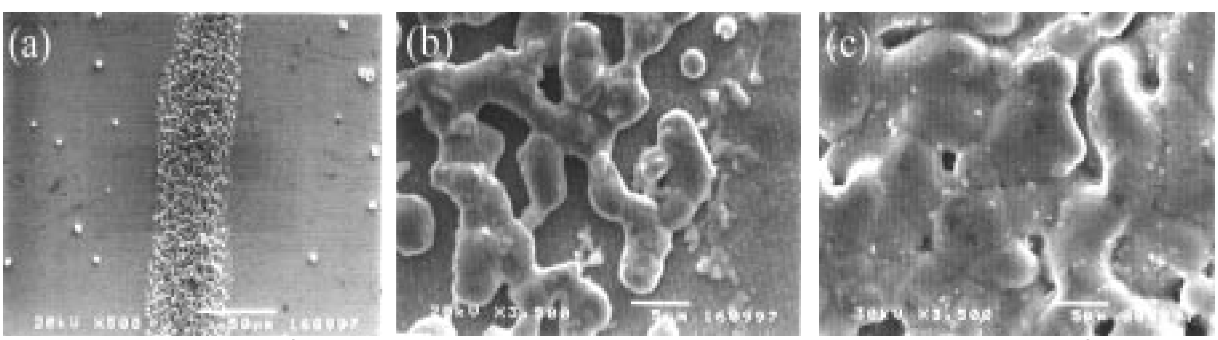


Fig. 2: SEM images of a 50 µm wide Ag line (a and b), and (c) is the morphology of a 0.1 µm thick CdS layer grown on a 100 µm wide screen-printed Ag line.

CdS layers were grown on Ag-lines/FTO/glass substrates by a chemical bath deposition method. SEM and EDX measurements were performed to study the growth of the CdS layer on FTO and to determine the coverage of the Ag lines with CdS (Fig 1c). Uniform CdS layers with grain size of about 100 nm are obtained. On annealing at 450 ˚C the CdS grains coalesce and the grain size increases to ~500 nm. Optical transmission measurements also indicate the recrystallization of CdS layer, and that the Ag lines do not influence the optical properties of the CdS layer.

Sponsor: BBW/EU (JOULE Program)

PUBLICATIONS 1997

Microelectronics and Optoelectronics Laboratory

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