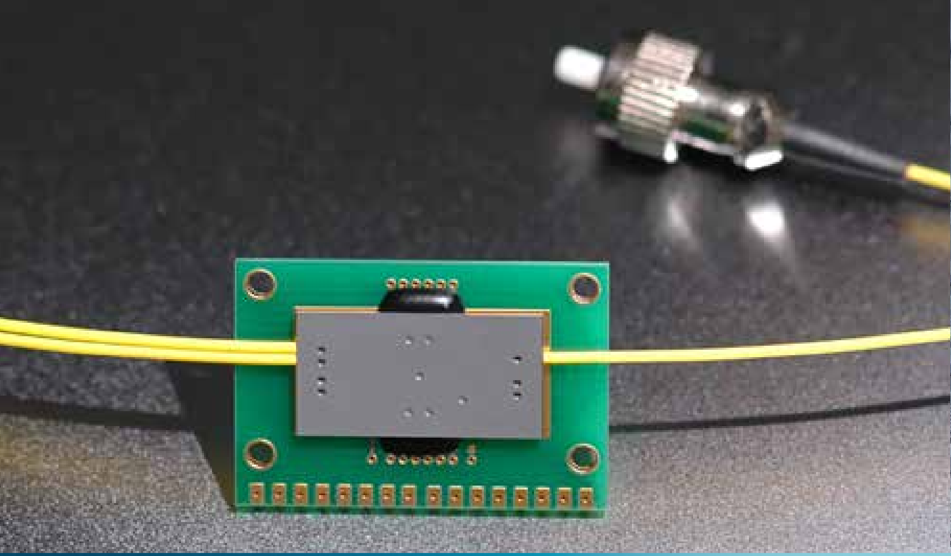

# Electro-optical liquid crystal waveguide switch

*Left: iber-optic coupled 1x2 liquid crystal switch*

*Right: 8˝ wafer with base parts of liquid crystal waveguide switches*

In optical telecommunication networks and fiber-optic sensor networks, the dynamic optical path control is realized through various control functions including optical switching. The ever-growing demands on switching performance as well as scalability and integration with other network devices pose continuously technological challenges on existing technologies. Fraunhofer IPMS develops innovative optical switches based on electro-optically induced waveguides (EOIW) in liquid crystals, which excel both in performance as well as capabilities offered by the underlying technology.

## Electro-optically induced waveguides in liquid crystals

An optical waveguide, i.e. EOIW, can be induced in a layer made from a material of large electro-optical (EO) constant by applying an electrical field across it, within regions delimited by stripe-shaped electrodes. Hence, a refractive index change is locally produced in this region, which serves as a waveguide core. Light coupled in this region is guided and can be collected at the waveguide output. Fraunhofer IPMS uses nematic liquid crystals in their isotropic phase as core materials for its EOIW based devices. The particularity of these liquid crystals is that they exhibit, when heated just above their nematic-isotropic phase transition, a remarkably large EO Kerr effect (with EO Kerr constants of about $10^{-10}$ m / V²). Accordingly, an electric field of a few V / µm applied on liquid crystals in this particular phase can give rise to local anisotropies in the order of $\Delta n \sim 10^{-3}$. This $\Delta n$ is large enough to permit the formation of a waveguide in the EOIW based device. In addition, these liquid crystals in their isotropic phase show excellent transparency over a broad spectral range as well as response times shorter than a microsecond. These are properties of utmost importance for the device performance.

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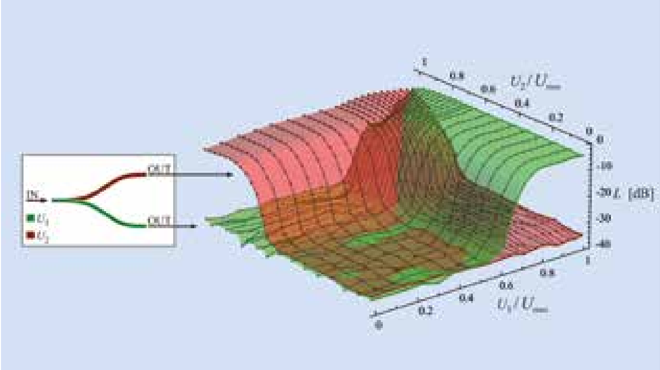
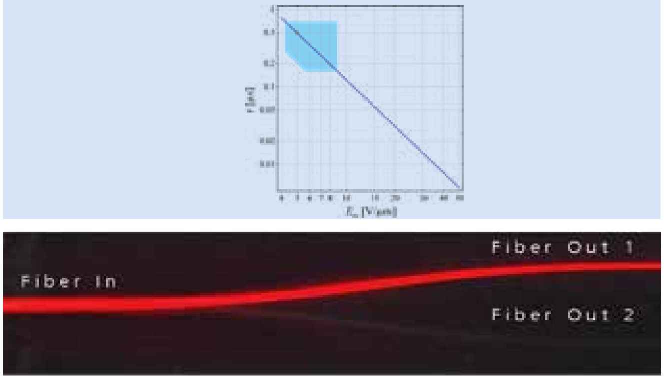



*Measured insertion loss vs.applied voltage for the two output channels.*




*Top: Switching time vs. the applied electrical field on the waveguide. The blue marked area designates the parameter space for currently available devices.Bottom: Input to output 1 switching by means of EO induced waveguides in the liquid crystal chip.*

## Design – Fabrication – Operation

Switches based on the EOIW concept are manufactured at the Fraunhofer IPMS by means of planar silicon technology. The Fraunhofer IPMS' optical switch chip is made from two processed silicon wafers – forming the base and the top parts of the chip – each including structured electrode stripes and low refractive index cladding layers. The image on the front (right) shows an image of the wafer with structured EOIW switch chips (i.e. the base wafer). The wafers are bonded together enclosing in between a layer made of liquid crystals. For device operation, an electrical field is applied between selected electrodes from both parts of the chip and across the liquid crystal layer. Light waves are guided on the paths, in this way "activated", at an optical loss of about 0.3 dB / cm.

Fiber-coupled 1 × 2 and 1 x 4 switch configurations have been designed and manufactured. Designs with a higher number of ports are available and custom designs are possible. The images on the top show the most important measured characteristics of the chip: insertion loss at the chip's two output channels and switching time. For the purpose of the demonstration of the EOIW underlying concept, the top bottom image presents a chip with the top part made of glass coated with ITO, which serves as the counter electrode. When visible light is coupled into the chip, the EO induced waveguide can be directly visualized.

## Advantages

Optical switches with no moving parts, such as the Fraunhofer IPMS' liquid crystal based devices, warrant high operation stability and reliability. The switch makes use of isotropic liquid crystals, which provide the device short switching times and excellent transparency over a broad spectral range. These devices are fabricated by means of high precision, planar silicon technology and therefore are suitable for high volume, cost-effective manufacturing. An additional benefit is that these switches can be integrated with other devices. Their design can be adjusted according to the desired application.

## Technology options

The technology of Fraunhofer IPMS proprietary EO induced optical waveguides permits, just by structuring of suitable electrode paths on the chip, the fabrication of optical switches with multiple inputs and outputs for single-mode operation. The Fraunhofer IPMS waveguide concept allows reconfiguration and programmability of induced LC waveguide functionalities from interconnection and switching to variable optical attenuation, variable power splitting or modulation with corresponding adaptations of the electrode backplane design and technology.

## Key Features

- Switching without moving parts (reliability)
- Fiber optic coupling to LC waveguide
- Full range variable optical power splitting
- Continuously voltage adjustable output optical characteristics (transmission)
- Wafer-scale fabrication with precision silicon microtechnology
- Scalability and reconfigurability of EO induced waveguide functions
- Integration capability with other devices on the same chip
- Customizable designs with multiple input and output ports

## Applications

- Fast switching in fiber optic sensor monitoring systems
- Optical telecommunication networks
- Laser technology
- Fiber-to-fiber interconnection
- Signal attenuation
- Spectroscopy
- Quantum computing

### Technical specifications

| Parameter | Unit | Value |
|---|---|---|
| Insertion loss* (at 1550 nm) | dB | < 1.5 |
| Attenuation range | dB | 0 - 40 |
| Wavelength range | nm | 400 - 1600 |
| Optimized for wavelength | nm | 1550 |
| Switching time | ns | < 100 |

** for TM polarization*