Wavelength division multiplexing (WDM) for secure optical data communication in industrial computers, process control and fabrication systems

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Abstract: - Optical data communication systems based on multi-channel architectures are discussed for security applications. We present micromachined tunable semiconductor / multiple air-gap filters based on stacked membranes, which are one of the key components in these multi-channel architectures.

Key-Words: - optical telecommunication system, wavelength division multiplexing, microsystem technology, DBR mirror, laser-waveguide

1 Introduction

Optical data communication systems are based on emitter devices (LEDs or semiconductor lasers), on optical guides (planar or buried waveguides, as well as silica or polymer fibres), on crossing nodes and on receiver devices (e.g. photodiodes). Using a single optical carrier frequency, these systems have a theoretical potential of about 200.000 Gbit/s in bitrate. Current systems are limited at the moment to about 40 Gbit/s due to limitations in stat-of-the-art devices.

To use multiple carrier frequencies (different colors of light) is attractive in fibre-optical telecommunication systems to increase the information bitrate. Using wavelength division multiplexing (WDM) allows to transmit about 100 communication channels on a single fibre, based on a comb of 200 individual wavelengths, where neighboring wavelengths differ about 0.4nm from each other. This increases the bitrate to 8000 Gbit/s on a single fibre. In addition, fibre cables contain e.g. 128 individual fibres. Hence, the total information capacity of such a fibre cable is 1024000Gbit/s. Fig. 1 shows the translation of the electronic bit patterns (e.g. current pulses) by lasers into corresponding optical bit patterns (sequence of ultra-short light pulses) which travel in the fibre towards the receiver. For each individual wavelength a laser is required (modified systems using tunable lasers or laser arrays will not be focused here). At the receiver side a tunable filter selects the channel of interest and thus only passes the desired information to a corresponding photodiode. The photodiode retranslates the optical bit pattern into an electronic bit pattern. The device combining the individual channels at the receiver side is called multiplexer, the device dividing the arriving light on different output ports is called demultiplexer. A complicated network is possible using nodes and add/drop/amplifier functions.

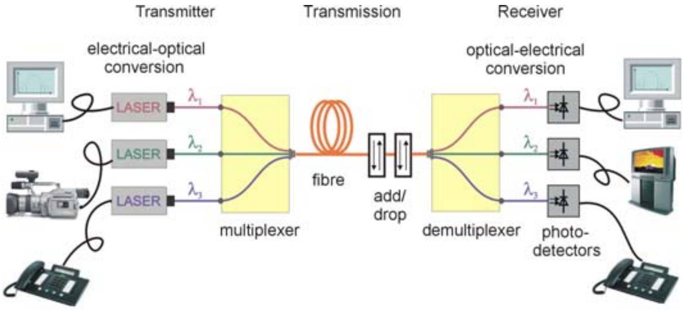

Fig. 1: Schematic of an optical telecommunication system based on wavelength division multiplexing (WDM)

For data communication, WDM might be highly attractive not due to the potential of an increase in information capacity but due to the security potential. Different information channels (different carrier frequencies i.e. different colors of light) can be applied for those information packages which have to be separated due to security reasons. Note that some advanced computer architectures are already based on optical communication. Today this is mainly used to reduce latence times. The information is transferred and distributed using optical waveguides. Very recent research activities are devoted to numerous methods for easy and cheap laser-waveguide coupling and waveguide-detector coupling [1]. Today mainly red emitting lasers availably from DVD technology are used in combination with polymer fibres. In future however green emitting lasers in combination might be of interest for data communication, since the optical loss in the polymer fibre is by far lower in the green spectral range compared to the red range. Fig. 2 depicts a schematic of a system combining 4 boards, several sensors and 2 PCs using 16 completely independent communication channels. Note that these numbers are arbitrary and can be matched to individual purposes.

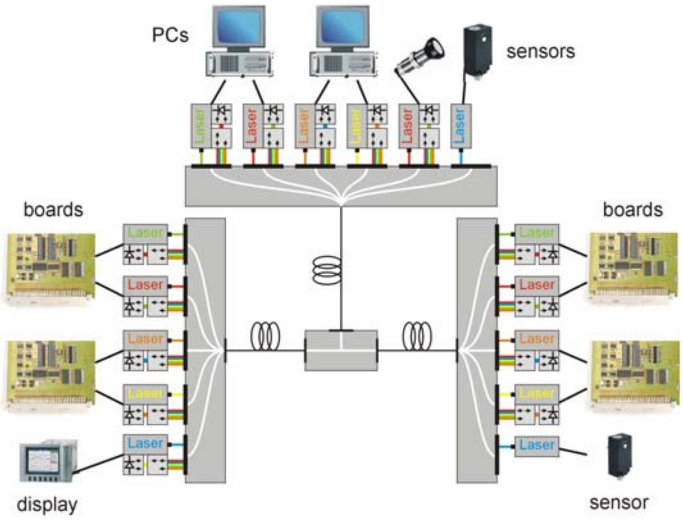

Fig. 2: Schematic of an optical data-communication system based on wavelength division multiplexing (WDM)

Nano- and Microsystem technology as well as photonics have an excellent chance to become the key note of our century. Microsystem technology describes a combination of at least two of the three disciplines micro-electronics, micro-optics and micro-mechanics. Our paper is devoted to the combination of all the three disciplines: micro-opto-electro-mechanical systems. In a schematic cross section, Fig. 3 demonstrates the channel tuning my micro-mechanically moving membranes (DBR mirrors). A multiple of half of the transmitted wavelength matches to the distance between the two mirrors.

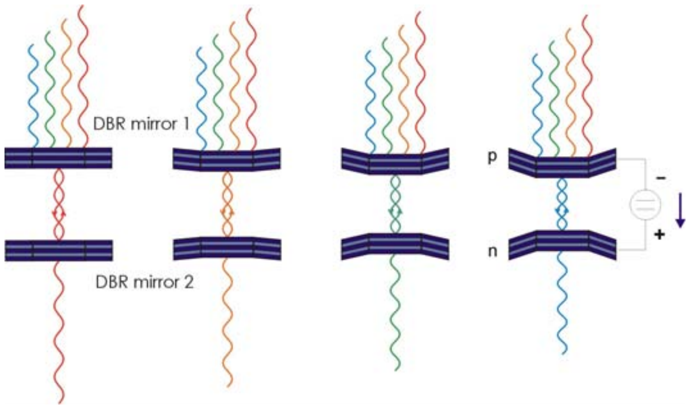

Fig. 3: Schematic spectral tuning of the filter, based on a single air-gap in this example.

Varying this distance by electrostatic actuation, the filtered (transmitted) wavelength is tuned.

In order to operate the filter devices at very low electrostatic actuation voltages we miniaturized the filters [2] and integrated further air-gaps in each DBR mirror (DBR=distributed bragg reflector). In the case of semiconductor DBRs, electrostatic actuation can be achieved by n-doping one DBR mirror and p-doping the other. Varying the reverse bias voltage of this pn-junction enables to control the central spacing. The technological fabrication on the basis of surface micromachining is described in detail in [2,3] and is based on 3 main steps: (i) definition of the multiple layer structure by epitaxy or other deposition methods, (ii) dry etching to define the lateral structure (vertical patterning of the mesa) and (iii) removing the sacrificial layers by selective wet-chemical underetching to generate the air-gaps.

Fig. 4 displays a scanning electron microscope image of a filter structure with four suspensions (resonator details in Fig. 5. The InP membranes have an optical thickness of $3/4\ \lambda$. The optical quality of the two surfaces of each membrane is defined by the quality of the epitaxial heterointerfaces. The surface micromachining fabrication process requires no micro-mounting since the entire structure is fabricated in a batch process. By varying the applied voltage from 0 V to 28 V we experimentally obtained a continuous tuning of the filter wavelength of 221 nm [4] as depicted in Fig. 6. To the best of our knowledge this is an improvement of our own international record value. Another device has provided 142 nm tuning using an ultra-low actuation voltage of 3.2 V.

The three figures underneath show scanning electron micrographs of semiconductor multiple air-gap filters with membranes and 4 suspensions, respectively.

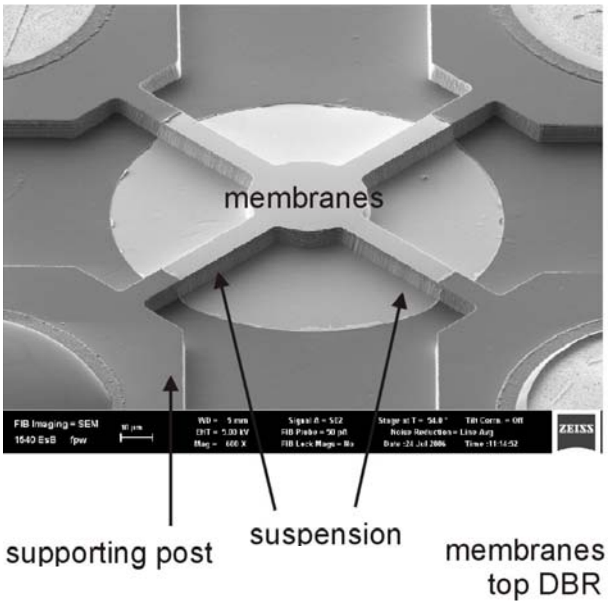

Fig. 4: GaInAsP/air-gap filter

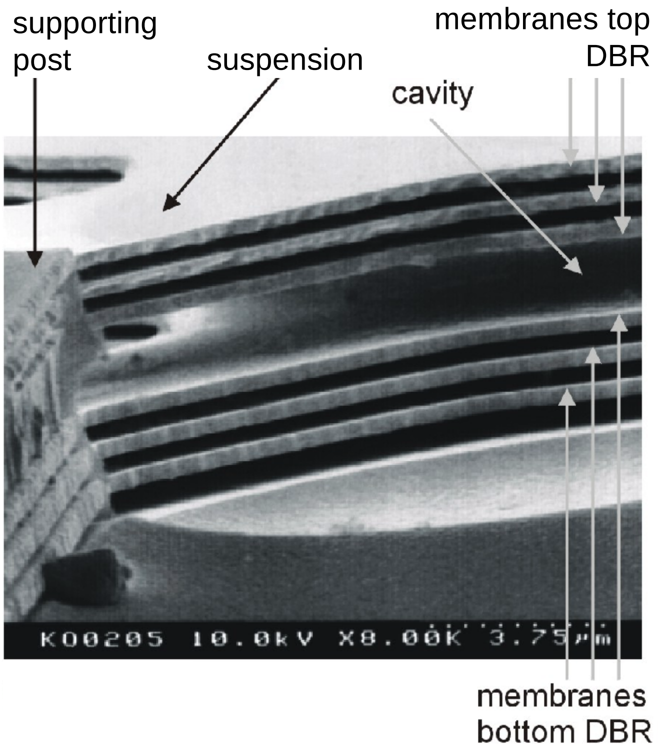

Fig. 5: detail

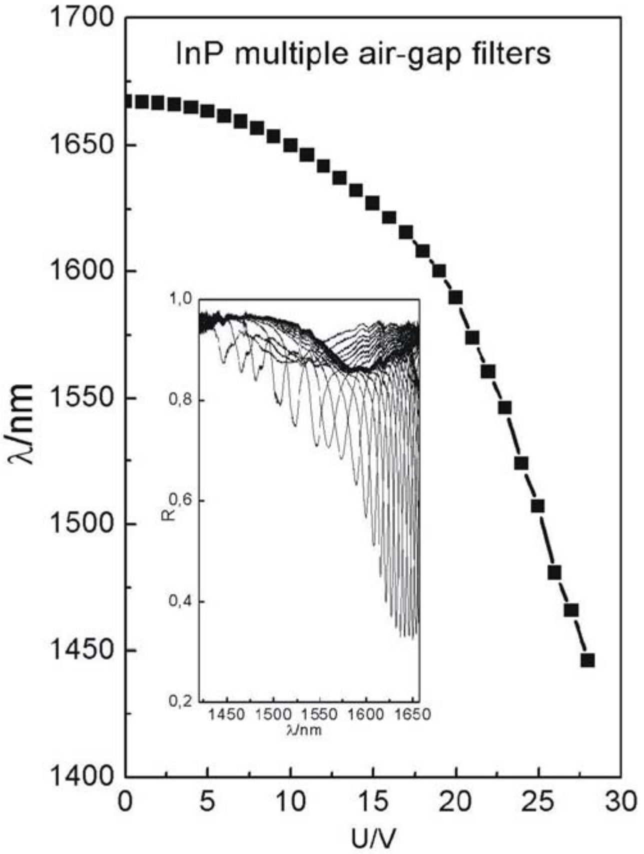

Fig. 6: experimental result of electrostatic tuning.

The financial support by the German Research Foundation DFG, is gratefully acknowledged. The authors thank J. Börcsök, K. Streubel, S. Irmer, J. Daleiden, D. Gutermuth, F. Römer, C. Prott, I. Kommallein, A. Tarraf, I. Wensch, A. Kricke and W. Scholz for technical support and stimulating discussions.

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