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Optical MEMS based on Silicon-on-Insulator (SOI) for Monolithic Microoptics

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Abstract: Microelectromechanical systems (MEMS) combined with optical components add optical functionality to devices and led to the terms Optical MEMS or MOEMS. The underlying technology of the presented devices is the silicon-on-insulator (SOI) based batch fabrication, which delivers small, reliable and lasting monolithic bulk silicon structures for commercial devices with the advantage of being very insensitive to temperature changes. The particular strength of the technology are monolithic horizontal and vertical micromirrors for a variety of applications.

Key Words: Microstructure devices; Couplers, switches, and multiplexers; Mirrors; Optomechanics;

1. Introduction

The significant influence of micro-electro mechanical systems (MEMS) in modern technology has led to many new and very small and well-controlled devices. In the optical domain MEMS components are becoming more and more relevant, particularly for the telecommunication industry and optical sensor technology [1].

In telecommunication industry are four main device domains: Amplifiers, switches or optical cross connectors (OXC), filters and variable optical attenuators (VOA). While optically pumped fiber amplifiers do not require any mechanical components, OXC, VOA, and filters are, however, based on mechanically or thermally driven elements and are hence relatively slowly working devices, which is widely accepted because of their use in slowly working routers and equalizers.

Besides for telecommunication components, MOEMS devices are also used in analysis instruments such as optical spectroscopes and they can reduce the size of such instruments considerably. Our step towards this optical domain is the MEMS based Fourier transform spectrometer (FTS).

2. SOI Technology

The IMT silicon bulk micromaching is based on 100 mm SOI wafers, which comprise a handle wafer as a base, a buried SiO_2 layer (1 to 2 µm thick), and a device layer (10 to 100 µm) on top made of single crystalline silicon (Fig. 1). It is an extremely simple technology with very few process steps, where deep reactive ion etching (DRIE) is utilized to pattern the device layer and the handle wafer. DRIE can create almost arbitrary 3D shapes. The SOI bulk micromachining is *very* different from both surface micromaching, which utilizes poly-crystalline silicon as a device layer, and classical bulk micromachining based on KOH etching, where silicon crystal planes constrain the patterning considerably. The DRIE-patterned surfaces can be made optically flat on top and sidewalls and the structures have excellent mechanical properties and show no fatigue. Due to the thickness of the structures, coatings and metallization of the devices have very little or no influence on the shape of the structures. The DRIE also allows producing highly accurate U-shaped guiding structures for optical components such as optical fibers. The pre-alignment is in the sub-µm range.

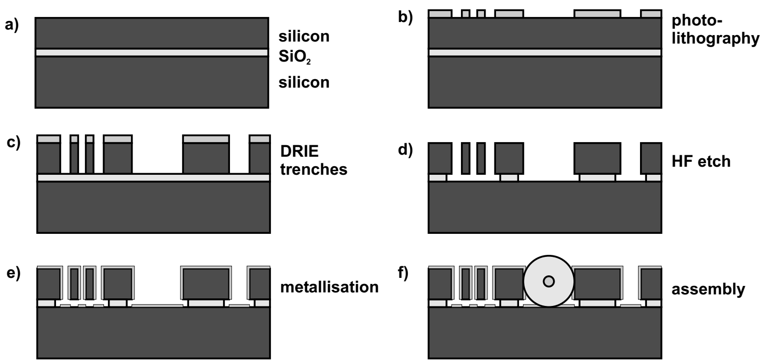

Fig. 1. SOI technology: a) The SOI wafer is a composite of a silicon substrate wafer, a buried SiO_2 layer, and a device layer. b) and c) The wafer is patterned by DRIE utilizing a photoresist mask. d) The structures are released by wet-etching the SiO_2. e) The metallisation improves the surface conductivity and reflectivity. f) Integrated alignment structures assist in the assembly of µ-optical components.

3. Micromirrors for Optical Switches (OXC) and Fourier Transform Spectrometers (FTS)

The first SOI development was a *2x2 fiber OXC*, which is now commercially available via the company Sercalo. The 2x2 OXC has two input and two output fibers [2]. The four fibers sit in U-grooves and are oriented at right angles to each other. Their endfaces all meet at one point, where an extremely smooth and movable gold-coated mirror is located. In a further development a 1x4 switch was microfabricated, which has 1 input and 4 output fibers. In both cases, the mirrors are attached to a beam that is electrostatically actuated by comb drives (Fig. 2a).

The optical loss in the switch is minimized by completely surrounding the optical components with refractive index matching fluid, which reduces both the refractive index step and the beam divergence in between the fibers. In the case of the 2x2 OXC, the insertion loss is less than 0.5 dB, the cross talk as low as -70 dB, and the switching time 500 µs. The live time was tested to be $5 \cdot 10^9$ cycles at 85°C.

FTS is a well-known technique to measure the spectra of a weak and extended light source whereas it offers a high signal-to-noise ratio. The MOEMS FTS utilizes the commonly used Michelson interferometer configuration with a scanning µ-mirror and occupies a total footprint of only 5x4 mm^2 (Fig. 2b) [3]. While the first approach was based on an external beam splitter, we are currently investigated different integration technologies. The optical path difference reached 77 µm and gained an optical linewidth for a He-Ne laser (λ=632.8 nm) of about 6 nm.

4. Variable Optical Attenuator (VOA)

Classically, VOA's are based on a light-shutter configuration that varies the optical intensity between two opposing fibers or collimators. In a novel joined approach we are fabricating a VOA based on a set of 16 µ-mirrors (Fig. 2c) [4]. The size of the mirrors is chosen such that each mirror reflects the intensity of one bit, yielding 16 intensity levels, which corresponds to 16 bit. Thus the light intensity is digitally modulated, rather than continual and highly non-linear as it is the case with shutters.

5. Acknowledgement

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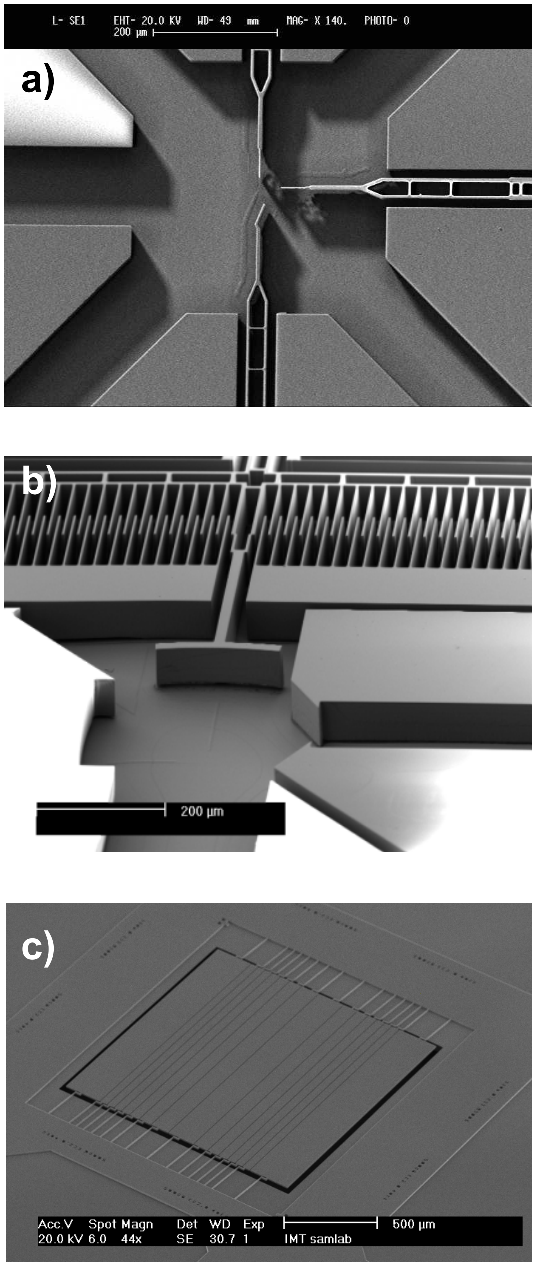

Fig. 2. Micromirrors: a) For an 1x4 optical cross connectors (OXC) each mirror is highly accurately pre-aligned with an optical fiber via U-grooves. b) In the FTS (Michelson interferometer) the scanning mirror also collimates the light in one dimension to increase the coupling efficiency between the in- and output fibers [3]. c) In a new joint approach of a VOA each of the 16 µ-mirrors represents one bit of a 16 bit intensity modulation [4].

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