Mechanical tuning of optical race-track ring resonators


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Abstract

This paper presents the fabrication and mechanical characterization of electrostatically actuated micro bimorphs integrated with race-track ring resonators, for optical tuning applications. The bimorphs, having an upward deflection in the off-state, are integrated by surface micromachining techniques with race-track ring resonators fabricated on Silicon On Insulator (SOI) wafers. Using electrostatic actuation, these bimorphs are pulled into the evanescent field of the ring resonator thereby modulating the propagation properties. Pull-in voltages of the bimorphs have been measured statically and the effect of electrostatic spring softening (ESS) on the resonance frequency has been measured dynamically. The resonance wavelength of the optical ring resonator could be tuned by 50 pm by applying an 8.5 V DC voltage to a 40 µm long bimorph, bringing it into close proximity of the ring resonator waveguide. To the best of our knowledge, this is the first experimental demonstration of tuning of race track ring resonators by integrated, electrostatically actuated bimorphs.

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1. Introduction

Microring resonators have been attracting attention in recent years due their compactness, high quality factor, ease of fabrication and potential for dense integration. They are highly promising building blocks in the field of integrated optical systems, having wide range of applications including lasers, optical switches, tunable wavelength filters, add/drop multiplexers and biosensors [1]. Tuning the response of the micro ring resonator makes it possible to use it as active elements in future optical communication network systems. One of the tuning methods is to change the refractive index of one or of all the materials of the ring resonator, which in turn changes the modal propagation constant and therefore the ring’s resonance wavelengths. The modal effective index of the resonator can be tuned by a variety of means like thermo-optic, electro-optic, opto-optic, micro-mechanically etc. [2]. Among these methods mechanical tuning by electrostatic MEMS has its advantages, as it has broad wavelength tuning range and requires very little energy for operation. When a bimorph beam is brought into the evanescent field of the
resonator waveguide, its modal effective refractive index and quality factor are changed. Tuning also allows to compensate for small fabrication-induced variations of geometrical parameters, changes in material parameters by temperature variations etc. Micromechanically-actuated wavelength-selective on/off-switching of a silicon-nitride micro ring resonator, by moving a lossy aluminium membrane into and out of its evanescent field, has been demonstrated with a 2 kHz, 0 V to 30 V square wave [2]. In a different approach, 1.7% wavelength tuning of a silicon nitride ring resonator has been demonstrated by perturbing the evanescent field with an external silica fiber probe [3]. In this contribution we describe the fabrication, mechanical characterization and optical tuning of MEMS actuators integrated with silicon race-track ring resonators designed for operation in the optical communications C-band.

2. Design and Fabrication

2.1. Design

Race-track ring resonators were designed to have a bend radius of 10 µm and a straight section length of 12 µm. The gap width between the port waveguide and the straight section of the ring is designed to be 250 nm. Figure 1 (A) shows a schematic illustration of the top view of the integrated device. The resonators and their access waveguides have been fabricated on SOI wafers by the silicon photonic platform ePIXfab [4], established at IMEC, Leuven. The thickness of the silicon device layer is 220 nm and that of the handle wafer is 700 µm, where the ring resonators are formed by etching 200 nm deep into the Si device layer. The lower cladding is a 2 µm thick thermal oxide (refractive index \( n = 1.45 \)) and the upper and side claddings are air (\( n = 1.0 \)). The race-track resonator has a free spectral range of 6.6 nm at 1550 nm. The integrated bimorph discussed here consists of an upper layer which acts as the electrode and a lower layer as the dielectric, where the thermal mismatch between them and the deposition-induced stresses make it bend upward in the off-state [5]. The modal field of the ring resonator has an exponentially decaying evanescent field which extends typically only a few hundred nanometers into the air cladding. The thickness of the upper electrode layer is optimised to have a sufficient upward deflection so that in the off-state, the tip of the bimorph is not strongly affecting the modal propagation properties. On application of a voltage between the upper electrode and the handle wafer, the bimorph is pulled towards the resonator. As the distance between the bimorph and the resonator decreases, the upper air cladding is replaced by the dielectric material of higher refractive index thereby changing the modal propagation properties and hence detuning the resonator. We have fabricated bimorphs with lengths varying from 40 µm to 100 µm at a fixed width of 10 µm for all cases. Figure 1 (B) shows the SEM image of the fabricated device whereas the inset shows the released bimorph on top of the coupling section.

Fig. 1. (A) Schematic illustration of the top view of the integrated device (B) SEM image of the fabricated device; inset shows released bimorph.

2.2. Fabrication

Figure 2 shows the fabrication flow for the integrated devices. (a) Starting with SOI wafers, on which the optical resonators are already fabricated, a 40 nm thick (\( n = 2.202 \)) low stress LPCVD Silicon Rich Nitride (SiRN) layer is deposited (b) as a protective layer for the thermal oxide cladding layer during the Sacrificial Layer Etching (SLE). This SiRN layer is removed from the backside of the wafer by reactive ion etching in order to have access to the
lower silicon electrode. (c) Next a 196 nm thick Tetra Ethyl Ortho Silicate (TEOS) oxide sacrificial layer \( (n = 1.465) \) is deposited conformally (LPCVD). This layer determines the vertical gap between the base of the bimorph and the ring resonator. (d) Then a 1097 nm thick SiRN layer \( (n = 2.25) \) is deposited as the bimorph device layer. (e) On the front side of the wafer, a 50 nm thick gold layer is sputtered as the upper electrode over a 8 nm thick chromium, applied as an adhesive layer. (f) After pattern transfer from the mask, gold and chromium layers are etched by wet chemical methods and (g) the SiRN layer is etched by reactive ion etching. (h) Directly after this, the sacrificial layer is etched by BHF (1:7) followed by the freeze drying release technology [6]. The thickness of the protective nitride layer is selected in such a way that during SLE this layer is not completely removed and still acts as a thin protective layer for the underlying thermal oxide layer.

Fig. 2. Fabrication flow of the integrated devices.

3. Mechanical and Optical Characterization

The integrated bimorphs are both statically and dynamically characterized in order to characterize the mechanical performance. Figure 3 (A) shows the off-state tip deflections of the bimorphs at various design lengths measured at atmospheric pressure by White Light Interference Microscopy (WLIM, Polytec MSA400). The off-state tip deflection is the distance between the tip and the base of the bimorph and it is increased as the length of the beam is increased. Figure 3 (B) shows the static pull-in measurements at atmospheric pressure by WLIM for a bimorph of 60 µm design length which has a pull-in instability point at a DC voltage of 5.1 V.

Fig. 3. WLIM measurements showing (A) Off-state tip deflections of bimorphs of various lengths and (B) static tip deflection measurements as a function of applied actuation voltage for a bimorph of 60 µm length.

The dynamic mechanical characterization includes measurements of the reduction of the first mode resonance frequency on application of a DC voltage (Figure 4 A) which is referred to as electrostatic spring softening (ESS) [7]. This measurement is carried out by a Laser Doppler Vibrometer (Polytec MSA400) at a pressure of 0.16 mbar in order to avoid the effects of squeeze film air damping. For optical tuning measurements, infra red light from a tunable laser (input power of 1 mW) is coupled to the input waveguide with the help of a cleaved fiber and end grating couplers. The transmitted light from the through waveguide is detected by a photodetector. Results of the
tuning experiments are shown in figures 4 (B) which shows 50 pm tuning of the resonance wavelength of the race-track ring resonator with a bimorph of length of 40 µm having a pull-in voltage of 9.5 V.

Fig. 4. (A) Resonance frequency shift due to ESS for bimorphs of various lengths measured by Laser Doppler Vibrometer (B) Optical measurement showing resonance wavelength shifting due to mechanical tuning with a bimorph of length 40 µm.

4. Conclusions

A technology for integration of cantilevers on silicon integrated optic devices has been reported. The Technology uses conformal deposition and sacrificial layer-etching to obtain self-aligned structures. A MEMS integrated race-track ring resonator has been fabricated successfully on SOI wafers and its mechanical and optical characterization has been carried out. This electrostatically actuated integrated device has been fabricated on wafer scale with CMOS compatible technology and has wide applications especially for integrated optic systems for application in the field of telecommunication networks, e.g. as a wavelength routing element. 50 pm wavelength tuning of the resonance wavelength has been demonstrated. The bimorph has been further mechanically characterized for off-state deflection, pull-in voltage and resonance frequency.

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References