Individually tunable silicon Bragg reflectors

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Abstract -- We introduce an innovative design of a tunable optical filter. The design constitutes of a vertical Bragg grating microfabricated in the device layer of a silicon-on-insulator (SOI) wafer and whose silicon walls can be independently operated to select the desired response of the filter. The design concept and detailed microfabrication process are presented.

I. INTRODUCTION

One-dimensional photonic crystals, especially tunable ones offer a wide range of possibilities as they are being integrated into Micro-Opto-Electo-Mechanical Systems (MOEMS). As a matter of fact, their band gap provides very selective filtering [1, 2] and making it controllable can lead the way to many applications. For example, in optical telecommunications, they could come in very handy in WDM networks where they can be used to select the increasing number of channels being carried at the same time. Quite a few devices using Bragg gratings have been elaborated: at first, there were mostly out of plane structures made with alternating layers of semiconductors [2]. Contrarily to fiber gratings that are directly "written" in the optical fiber, microfabricated gratings are external devices that offer a more flexible and easy to integrate alternative. More recently, in-plane designs with mirrors vertically etched in the substrate have attracted more attention, despite the challenge they represents in terms of microfabrication [3]. In addition to permitting the integration of an increased variety of tuning mechanisms, these designs facilitate optical fiber alignment. That makes them highly attractive as demultiplexing devices or wavelength selectors for broad band laser sources. Their use can also be considered as mirrors for fiber lasers and in biomedical applications; they could for example be used to determine the refractive index of a liquid filling the air gaps since the observed reflection would depend on it.

II. CONCEPT

The proposed design is innovative in quite a few ways. As many of the tunable optical filters that are being developed lately [3-5], it aims to be very compact, highly reproducible, and controllable; but more than that it is intended to be tuned in a faster and more precise way and to allow a larger tunable range of bandwidths. It also presents the unique feature of moving each individual reflector. To achieve these goals, a MOEMS constituted of vertical silicon Bragg mirrors controlled individually by electrostatic comb drives is proposed.

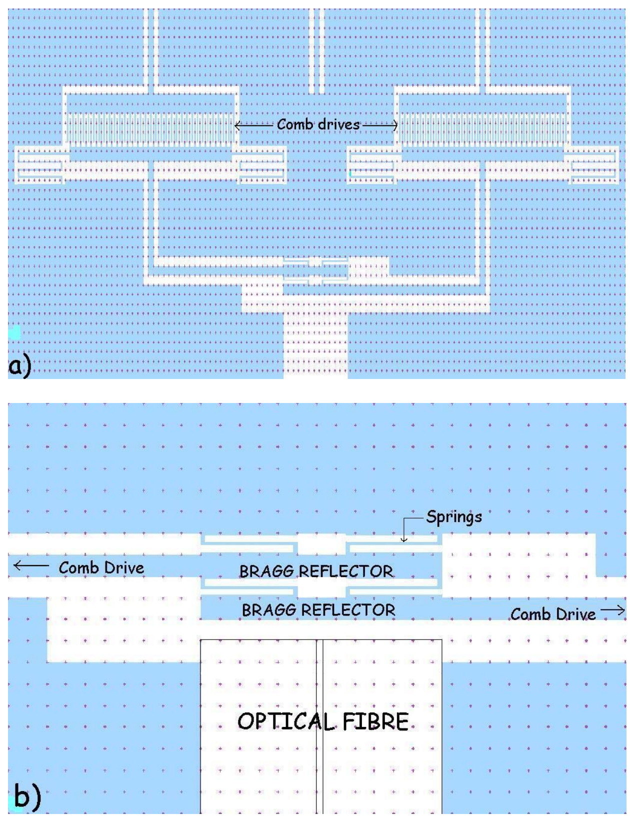

Figure 1. Schematic drawing of the device: a) overview; b) inset.

The use of silicon, apart from being very economical and relatively easy to process, allows going a step further in the compactness. As a matter of fact, the high refractive index difference between silicon and air makes it easier to get a high reflection with only a few periods (as low as 2 or 3!)

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[4]. Moreover, to reach a higher alignment precision for optical fiber, the Bragg mirrors are microfabricated in-plane and the wavelength selection is done by reflecting the desired one. In that case, there's no need to align two fibers (one on each side of the walls) and there is a groove that allows placing the fiber in plane, right in front of the walls. Finally, the individual control of the walls with electrostatic comb drives, which provide faster and much more reliable tuning than thermal actuators that are often seen [6], gives even more flexibility to the device.

III. FABRICATION

The device is fabricated in a SOI wafer that has a 10µm device layer, 2µm box and 500µm handle. A first lithography step is done to pattern the pads which will be metallized by lift off with a very thin layer of gold. Then, a second lithography is realized to pattern the device layer. The etching is done by Deep Reactive Ion Etch in an Inductively Coupled Plasma (DRIE ICP). We use Shipley S-1813 photoresist because it provides good lithography resolution up to micron precision and has an excellent dry etch selectivity (1: 33, experimental), which is sufficient for the depths that we want to reach in this device. To smooth the scalloping produced by the deep etch and obtain optically efficient surfaces, the parameters have to be optimized, therefore, low ICP and RF powers were used (350W and 10W respectively) with very low etch times and even lower passivation times (5s and 3s respectively). Moreover, a slight amount of O_2 was introduced during the etching step and a short thermal oxidation followed; that oxidation step was added to help smooth even more the scalloping and will be etched away during the final release. A third photolithography step is executed to pattern the optical fiber grooves: first the oxide at the bottom of the grooves is removed by Reactive Ion Etching (RIE) and then 51µm of the handle are etched so that the entire core of the fiber will face the reflectors. Finally, the structures are released using a vapor HF system (Idonus) that operates with concentrated HF (49%) at ambient temperature on a slightly heated (30-40ºC) substrate to avoid stiction.

Aknowledgements:
We thank Natural Sciences and Engineering Research Council of Canada (NSERC) for financial support of this work.

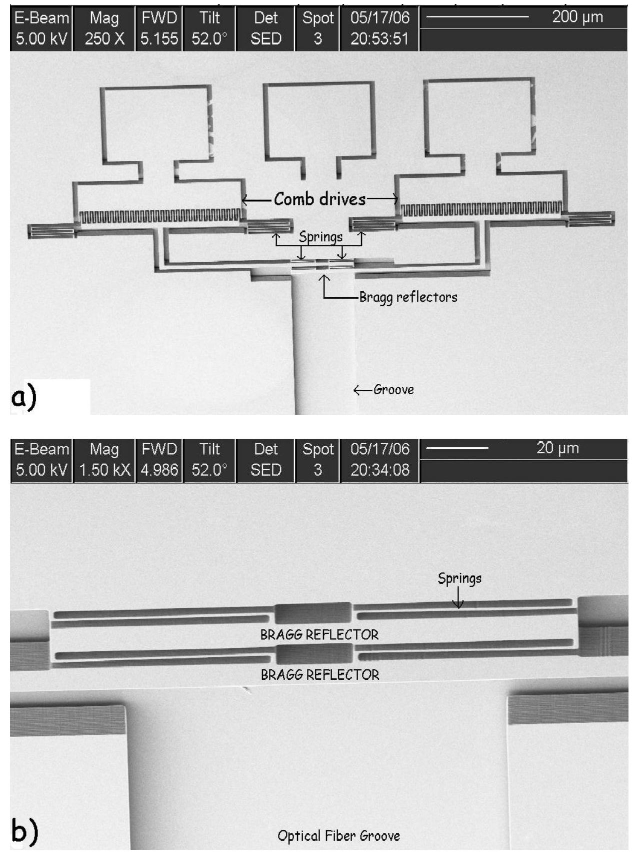

Figure 2. SEM photograph of a complete device including fiber groove, Bragg reflectors, springs and electrostatic comb drives: a) overview; b) inset.

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