Micro-mechanical Integrated Optical Structures

Fabricated through physical micromachining and direct UV writting

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***Abstract*—The work presented, reports recent developments in the fabrication of micro-mechanical integrated optical components. Combining physical micromachining and direct UV-writing, micro-membranes micro-cantilevers and micro-bridge structures are fabricated.**

Keywords-component; UV-writing; physical micromachining; micro-cantilevers; micro-membranes; micro-bridges

I. INTRODUCTION

Microelectromechanical Systems (MEMS) have revolutionized today's technology, with applications ranging from triggering mechanisms in automotive airbags to motion detectors in the latest smart phones. Analogous to these electronic components, similar constructions using optical means of detection are also finding increased niches of application. Such optical components carry the distinct advantage over electronic components in that they can operate in extreme environments (e.g. highly flammable environments and in areas of strong EM-interference). In addition to this environmental operation advantage, under certain detection modes these components can also have optical-multiplexing advantages and form part of distributed remote sensing networks via optical fiber connections.

The majority of micro-mechanical structures operate by exploiting the mechanics of certain architectures. These are typically low-mass structures that include membranes, cantilevers and bridge forms. These fundamental low-mass structures have all been exploited in the fabrication of optical micro-mechanical structures, for both planar and optical fiber based platforms [1-6].

Unlike previous developments of planar-integrated optical micro-mechanical structures, the components developed by this group have the unique advantages of not being limited to variations in source power, are more rugged than free-space alignment approaches and have the capability to spectrally multiplex signals. The reported components are fabricated from a silica-on-silicon platform, which is conducive to standard optical fiber connections, thereby allowing simple integration of devices into a distributed sensing network via standard fiber communication components.

The fabrication approach of these components is uniquely achieved through a combination of direct UV writing [7] and physical micromachining [5, 6]. Direct UV writing is used to write single mode waveguides and Bragg gratings whilst physical micromachining is used to construct the low-mass structures. Using this combination of fabrication methods, micro-membrane, micro-cantilever and micro-bridge components have been fabricated, as illustrated in Figure 1. Detection of physical changes to these microstructures is monitored through interpreting optical responses of a Fabry-Perot cavity. In order to permit multi-parameter multiplexing, Bragg gratings are used to form the Fabry-Perot cavity, either side of the structure, as illustrated in Figure 1. As these Bragg gratings are designed with equal period the cavity formed is spectrally selective, allowing multiplexed operations.

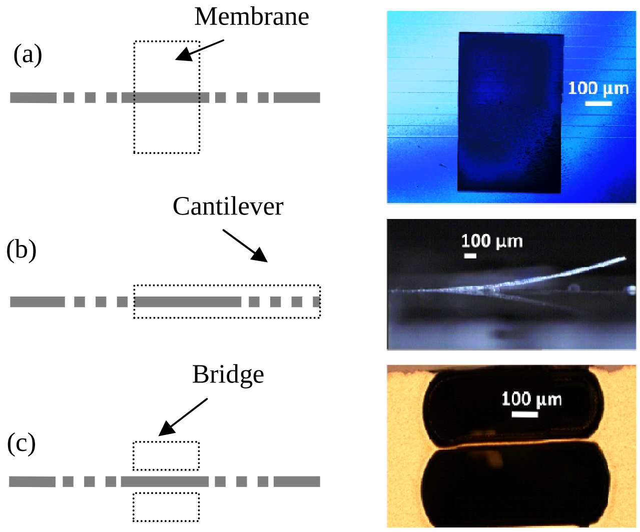

Figure 1 Images of the three micromechanical integrated optical components developed, indicating waveguide (thick grey) Bragg grating (dashed grey) and micro-mechanical component (thin black dashed line), for (a) micro-membrane (b) micro-cantilever (c) micro-bridge.

Deflection of the microstructures are monitored through changes in Fabry-Perot Bragg grating (FPBG) signatures. As the micro-structure mechanically deforms stress induced optical responses occur, altering the Free Spectral Range (FSR) of the Fabry-Perot fringes. Assuming the central Bragg wavelength of the FPBG is negligibly affected by the component's actuation, it can be used to compensate for thermal variations [6].

The method of fabrication permits such devices to be made as it indiscriminately removes both silica and silicon material and can create deep vertical structures. Another advantage of the fabrication techniques is that they do not require cleanroom processing or hazardous chemical etchants, such as HF acid.

II. FABRICATION

The reported devices are fabricated on a silica-on-silicon platform, achieved using flame hydrolysis deposition (FHD). Wafer construction begins with a silicon wafer with a thick thermally grown oxide (~15 µm). FHD core and underclad layers are subsequently deposited and consolidated. The core layer is doped with germanium and boron such to make it photosensitive to UV light, which is enhanced through hydrogenation of the wafer. Using a direct UV writing technique both waveguides and Bragg gratings are written into the core layer [7], with a frequency doubled argon-ion laser. The UV writing process uses a patented dual beam writing technology [7] to define waveguides and Bragg gratings in a single processing step. After UV writing physical micromachining is performed. This step physically removes silica and silicon material (depending upon the component to be fabricated) from the chip. A subsequent potassium hydroxide (KOH) etch is made to remove excess silicon material. After fabrication the chip is packaged by fiber pigtailing, as illustrated in figure 2. The pigtail is secured with UV-curing epoxy and is robust enough to survive mechanical testing.

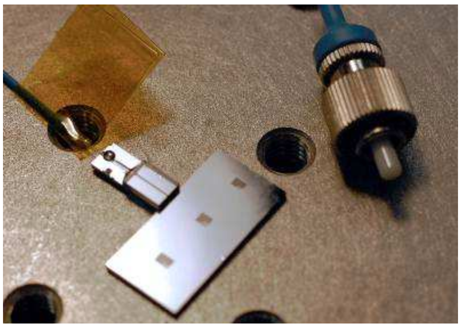

Figure 2 Photograph of three micro-membrane structures integrated into a single optical chip.

III. RESULTS AND DISCUSSION

Due to the high consolidation temperatures associated with FHD fabrication and the different expansion coefficients of silica and silicon, the thin (~50 µm) silica layers are under significant compressive stress. This stress results in buckling of the microstructure under particular conditions. Effects that result from this static buckling include:

- Spectral chirp in Bragg signatures
- Mechanical nonlinear responses
- An asymmetric response to physical actuation

Through considering these effects design optimization can be made. Furthermore these effects can be exploited to actually enhance the performance of the sensing component. For example, the pre-buckling of a membrane can be used to distinguish between positive and negative pressure differentials [6].

A typical FPBG signature, for a 5 mm long cantilever structure, is illustrated in Figure 3. This spectrum can be monitored with either a broadband source and Optical Spectrum Analyzer (OSA) or a tunable laser source and photodiode. It is understood that for slowly varying responses a broadband source and OSA, is best suited as the central Bragg peak can be used as a thermal reference the microstructure [6]. However, component sensitivity can be enhanced through monitoring the mechanical resonance, measured using the laser configuration and a lock-in-amplifier [8].

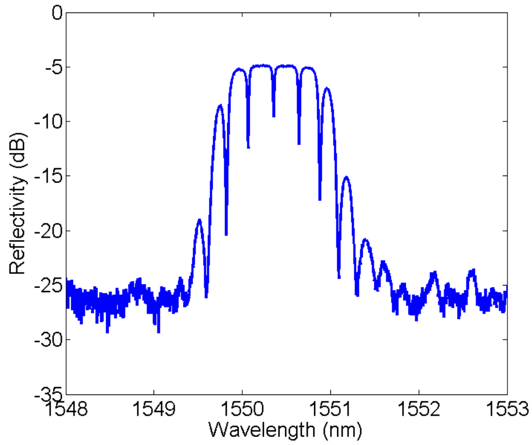

Figure 3 The Fabry-Perot Bragg grating signature of a 5mm cantilever device.

IV. SUMMARY

The latest developments in micro-mechanical integrated optical structures, fabricated using direct UV writing and physical micromachining have been reported. We shall summarize the latest results including design considerations and mechanically nonlinear phenomena arising from the large compressive stresses associated with fabrication. We shall report on the limitations to device footprint and sensitivity of detection.

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