In-Plane Transduction of Nanomechancial Microcantilever Motion To Enable Sensor Arrays

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ABSTRACT

We recently introduced a new microcantilever transduction mechanism that is designed to scale to large microcantilever arrays on a single chip while maintaining a very compact form factor and high sensitivity. It is based on an in-plane photonic approach that uses differential optical detection together with microcantilevers that form single mode rib waveguides. The basic operation of our differential measurement method has been experimentally verified.

Keywords: microcantilever sensors, sensor arrays, waveguide sensors, waveguide bends and splitters

1 INTRODUCTION

Microcantilevers show significant promise in sensing minute quantities of chemical and biological analytes in vapor and liquid media (see for example Refs. 1-4). Much of the reported work on microcantilever sensors has made use of single functionalized microcantilevers, usually derived from commercially available atomic force microscope (AFM) cantilevers. However, multiple microcantilevers are needed so that one or more can serve as a reference to obtain accurate and unambiguous measurements through the elimination of thermal drift, turbulence, and the effects of undesired chemical reactions and adsorption of molecular species on the underside of the sensor cantilever. [5] Moreover, arrays of microcantilevers with different bioselective coatings are needed for sensing a variety of compounds simultaneously and with unambiguous specificity relative to background molecular species in an uncontrolled environment. Hence development of arrays of microcantilevers is critical for biological sensor applications. In this paper we discuss our new in-plane differential microcantilever transduction technique.

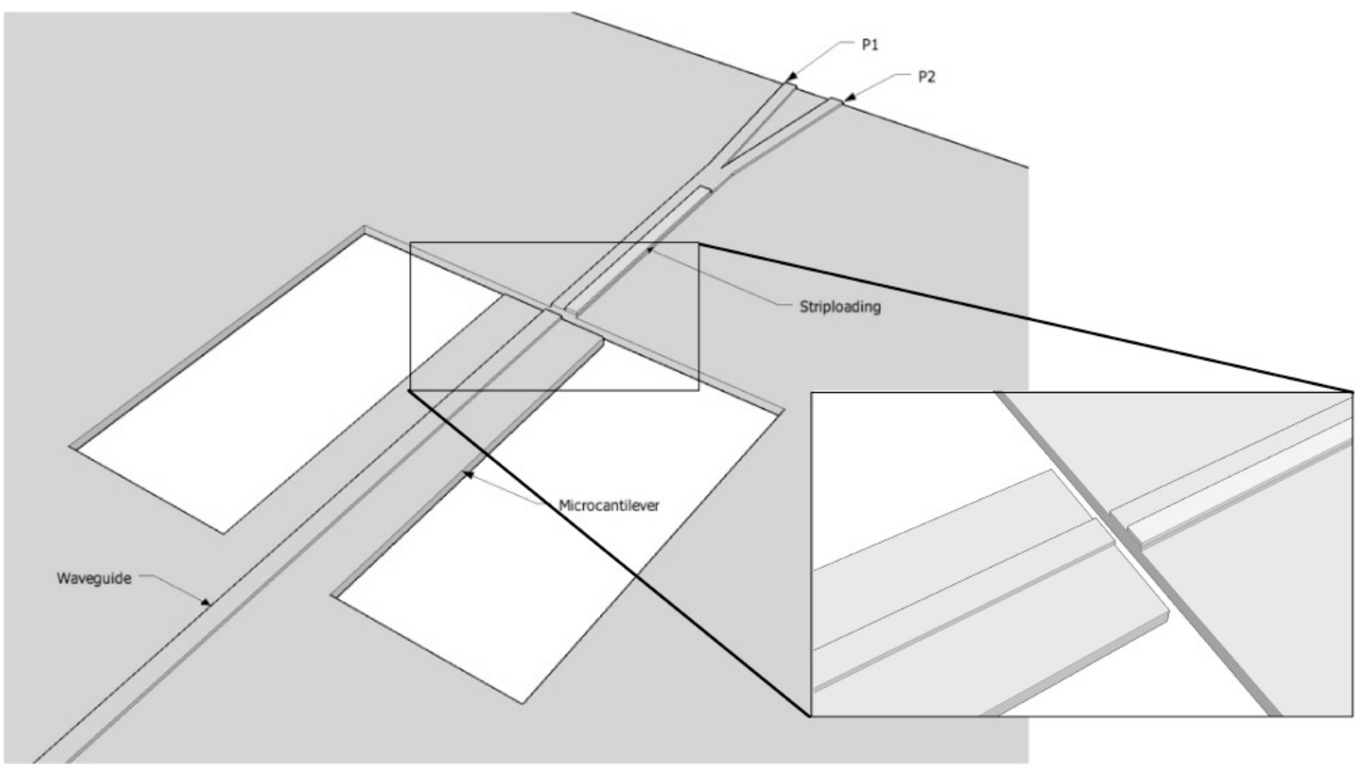
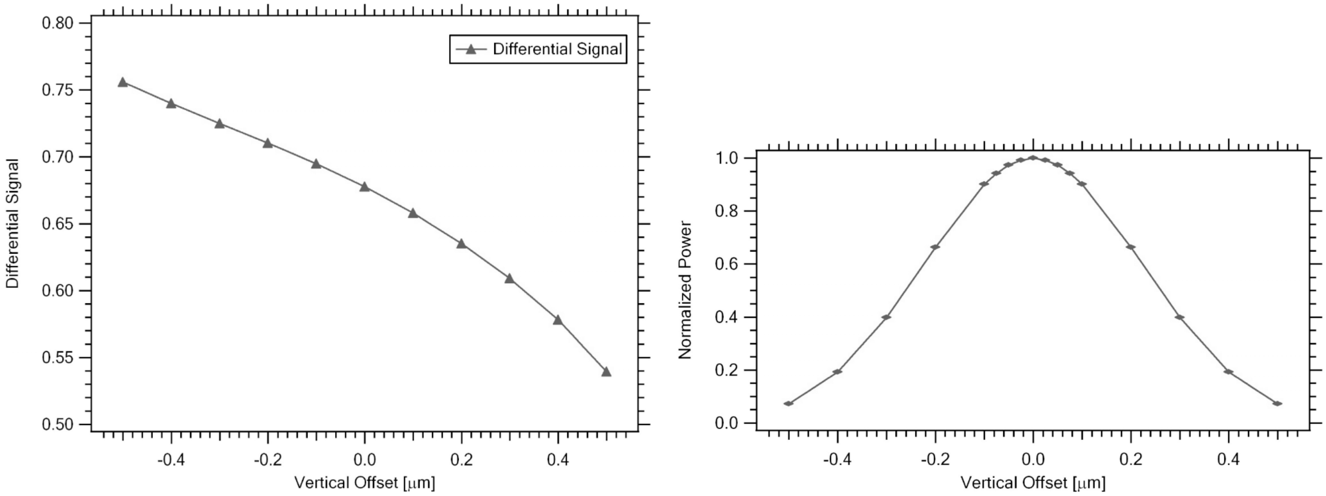


Figure 1. Schematic illustration of a microcantilever with a rib waveguide and a differential splitter located across a small gap from the microcantilever tip.



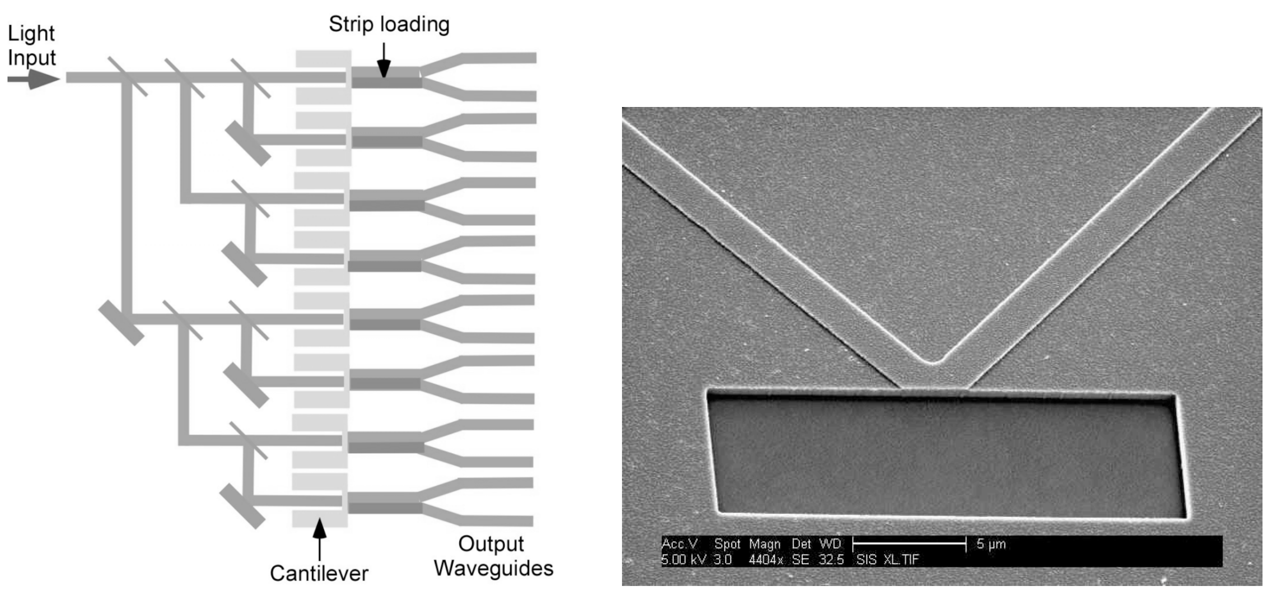
(a) (b)

Figure 2 (a) Differential signal calculated for a particular waveguide differential splitter. (b) Signal when only a simple receiver waveguide is used.

2 APPROACH

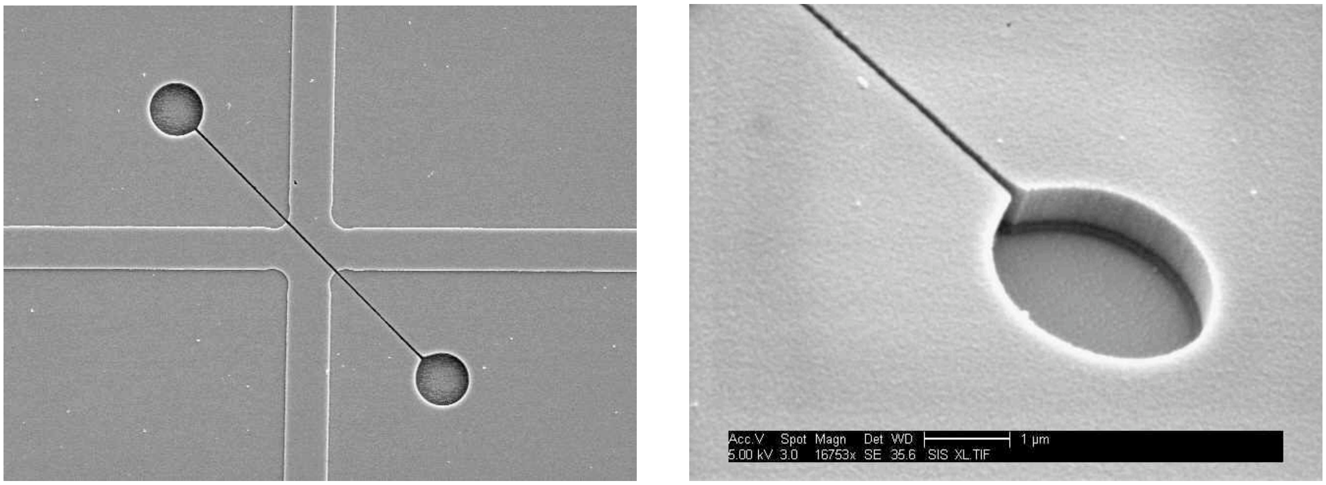
2.1 Microcantilever Transduction With A Differential Splitter

Unfortunately, the most sensitive microcantilever readout mechanisms (such as laser beam reflection as used for atomic force microscopy) are not readily scalable to large arrays. We therefore introduce a new microcantilever transduction mechanism designed to scale to large arrays while maintaining a very compact form factor and high sensitivity. [6] This mechanism is based on differential optical detection of the cantilever tip position in which the cantilever itself forms a single mode optical waveguide as illustrated in Fig. 1. The differential splitter located across a small gap from the microcantilever tip is designed to convert changes in microcantilever vertical tip position to a varying optical power splitting ratio in two waveguides that emerge from the receiving waveguide. This waveguide differential splitter permits differential detection of microcantilever deflection as calculated in Fig. 2(a). Note



(a) (b)

Figure 3.(a) Schematic diagram of microcantilever array with compact waveguide bend and splitter network. (b) SEM image of TIR bend without SU-8 covering. [9]



(a) (b)

Figure 4. (a) Top view and (b) oblique view SEM images of etched splitter trench prior to application of SU-8.

that the differential signal is a monotonic function of microcantilever deflection, in contrast to the response that would be measured with a simple capture waveguide as shown in Fig. 2(b). [The differential signal is formed as $(P_1-P_2)/(P_1+P_2)$.] In the latter case, there is minimal to no signal change for cantilever deflections near 0 μm since the slope there is close to zero or zero. Therefore an approach that yields a monotonic change in the signal as a function of deflection is much preferred.

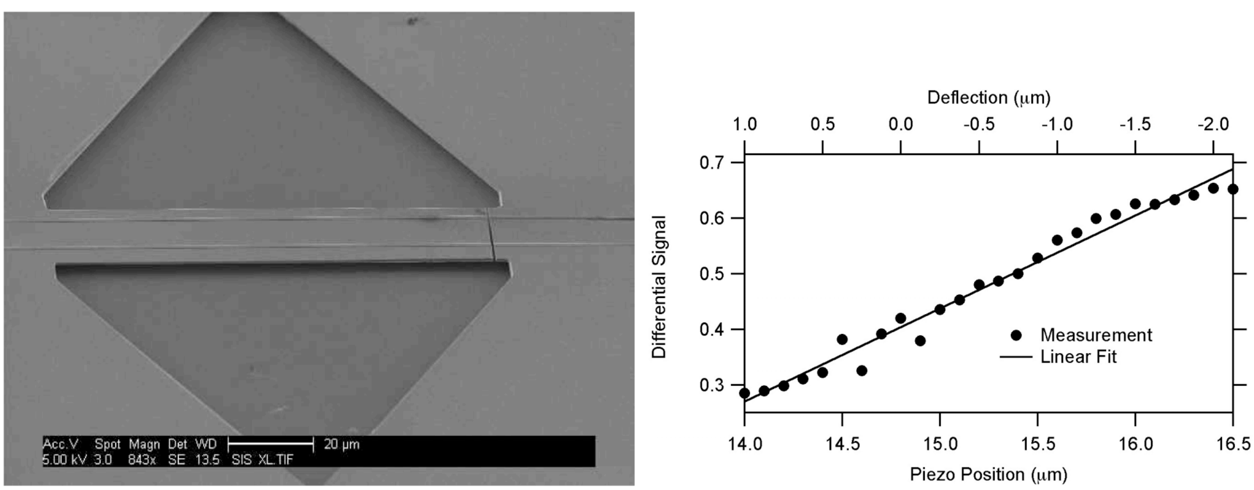
2.2 Microcantilever Arrays

A schematic illustration of a simple linear array of microcantilevers is shown in Fig. 3(a). A key element in reducing the size of such an array is to create compact waveguide bends and splitters. For the rib waveguides we use in our approach, the minimum bend radius for a conventional curved 90 degree bend is 1.2 mm, which is clearly way too large to hope to get hundreds to a thousand microcantilevers and associated waveguide elements on a single chip with a few square centimeter area.

We have therefore developed compact bends and splitters based on total internal reflection (TIR) and frustrated TIR [7,8], respectively, with trenches that are filled with SU-8, which also forms the waveguide overclad. An SEM image of a bend prior to SU-8 coating is shown in Fig. 3(b). As reported in Reference 9, with proper positioning of the trench interface with respect to the waveguide bend, low optical loss (0.32 dB/bend) can be achieved. A fabricated splitter trench is shown in Fig. 4.

3 MICROCANTILEVER DEFLECTION MEASUREMENT

As shown in Fig. 5(a), silicon microcantilevers have been fabricated in SOI. Measurements of deflection have



(a) (b)

Figure 5. (a) Fabricated microcantilever with differential splitter across small gap at end of microcantielver.
(b) Microcantilever deflection experimentally measured with differential splitter.

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been made with light at a wavelength of 1550 nm using differential splitters. An initial measured differential signal is shown in Fig. 5(b) as a function of microcantilever deflection (top axis). It is reasonably close to the expected differential signal based on simulation results, thereby demonstrating the basic feasibility of the in-plane differential splitter transduction approach. Further measurements are in progress to determine measurement sensitivity.

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