Metallic Nano Electro Mechanically Actuated Gripper and Tunable Nano Photonic Device

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With the increasing interests in nano scale science and engineering, the scaling down of MEMS technology to NEMS has been gaining interest. While the scale down of MEMS to NEMS opens the new window of opportunities, it also leads to challenges in processes, characterization, as well as fundamental understanding of the physics of the system. In this work, we present a fully functional sub-micron electrothermally actuated high aspect ratio metallic gripper and a MEMS-enabled silicon-based widely tunable nano-photonic device.

The design of the gripper was scaling down of the commonly known chevron thermal actuator. It is designed to be in normally open mode (close when actuated). ANSYS^{TM} simulation was carried out with the consideration of the limitation of process capability (minimum feature sizes and structural heights). The optimal dimensional parameters found were: width of the bent beam of 350 nm; thickness of the structure of 1 µm; and the angle of the bent-beam of 6º. In order to fabricate dense array of high aspect ratio sub-micron features, electron beam lithography using a LEO 1570 SEM equipped with the nanometer pattern generation system from JC Nabity Lithography Systems and polymethyl methacrylate (PMMA) resist was used. Extensive study was carried out and a process was developed that can create PMMA with trench width of 300 nm and thickness of 1 µm. For the fabrication of the sub-micron electrothermal grippers, 1.2 µm thick SU-8 was used as a sacrificial layer and the 1 µm thick PMMA was used as the electroplating mold. Low current density (~2mA/cm^2) electrodeposition was used to minimize the built-in stress in the metallic film and to grow very fine nickel grain. After the electrodeposition, both PMMA mold and SU-8 were removed by dry etch. In order to characterize the displacement characteristics of the sub-micron grippers, we loaded samples into a FEI dual beam focused ion beam (FIB) chamber which has a nanomanipulator system in it. The FIB chamber with the nanomanipulator system not only provides very high-resolution images, but also provides a controlled characterization environment. Hewlett Packard 4155A semiconductor parameter analyzer was used as a precise current source to the gripper through the two nano probes of the nanomanipulator system. A series of SEM still images and video were taken during the operation of the grippers and the amount of the displacement were measured on the screen using the reference lines and the distance measuring feature of the dual beam FIB. Reproducible deflections of up to 1.39 µm were observed with 11.2 mW of input power which corresponds to the input current of 28 mA and the applied voltage of 400 mV.

To our knowledge, for the first time, negative refraction based on the superprism effect is reported in a 2-D silicon-based photonic crystal device. This work has a huge potential in various applications employed within silicon-based photonic crystal systems such as super-lenses, tunable filters, and optical switches. The device, designed for 1.54 µm infrared light, is composed of a triangular array of silicon pillars of diameter 370 nm with a lattice spacing of 616 nm embedded in a thin 400 nm thick polyimide matrix. Small changes in the incoming angle of light can produce large changes in the direction of the outgoing light near zero stress. Silicon pillars are formed by RIE etching and polyimide is then spun on, baked and etched to form the photonic crystal (PhC) device. The PhC matrix is then released from the oxide with a BOE etch and methanol-based stiction-free dry rinse. Samples with incident angles in the range of 0º ~ 8° have been tested. *Strong negative refraction* on the order of 50° is seen in the PhC with the incident angle of 8°. This is in close agreement with the simulated results and clearly demonstrates the effectiveness of the photonic crystal device.

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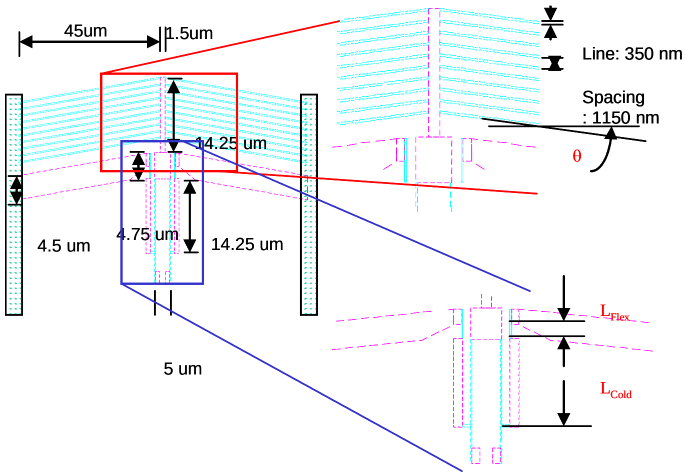


Figure 1. Schematic diagram of the sub-micron gripper design.

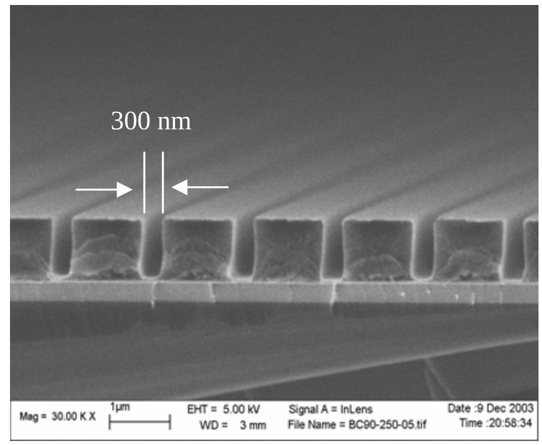


Figure 2. SEM image of high aspect ratio sub-micron electron beam lithography in PMMA.

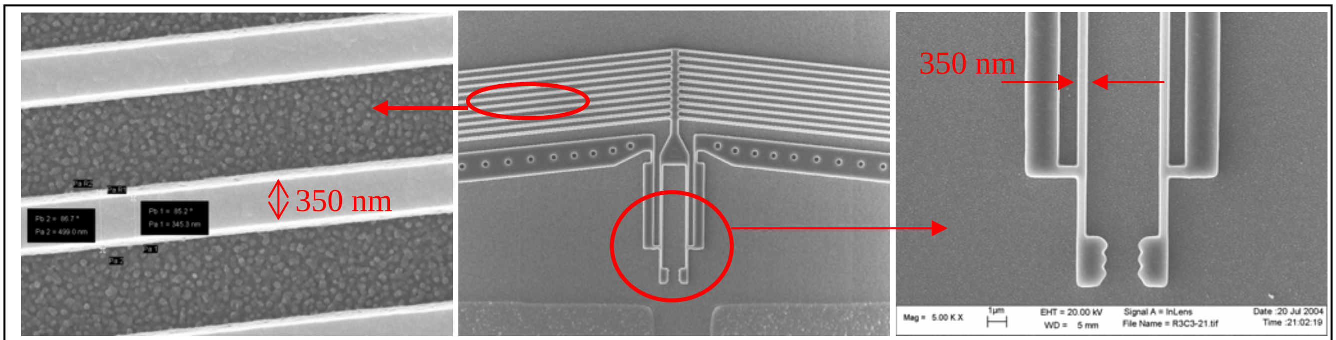
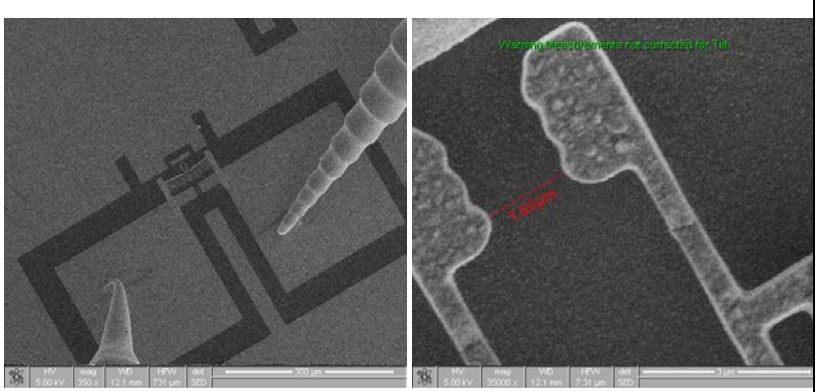


Figure 3. SEM images of a fabricated suspended submicron metallic electrothermal gripper with the bent-beam width of 350 nm, the gripper jaw opening of 2.1 µm, and the structural thickness of 1 µm.



(a) (b)

Figure 4. SEM images of: (a) the probes and the sub-micron gripper under test; (b) the gripper jaw opening (1.6 µm) with the applied current of 20 mA (4mW, 200 mV).

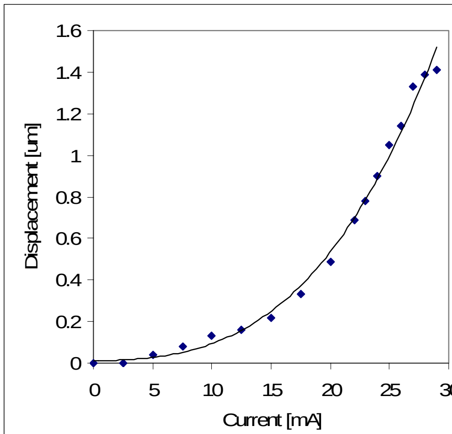
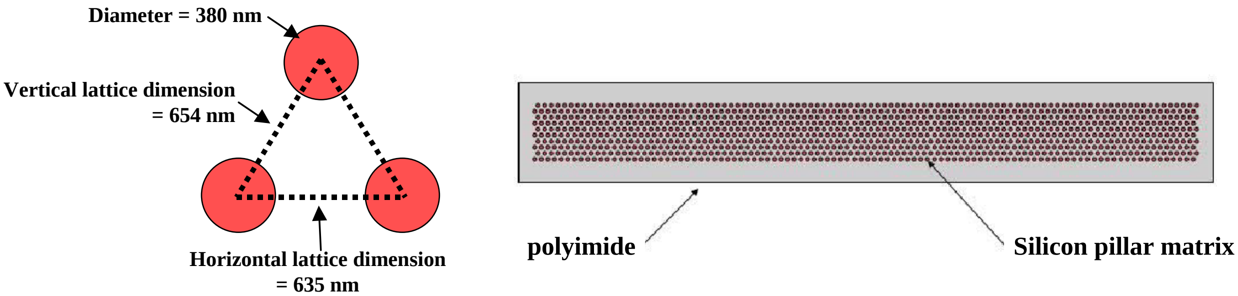
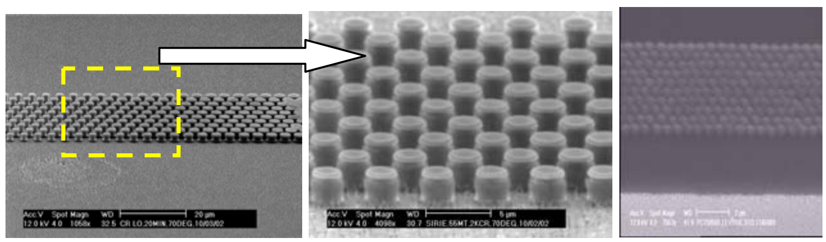


Figure 5. Amount of displacement of the sub-micron gripper as a function of the applied current.

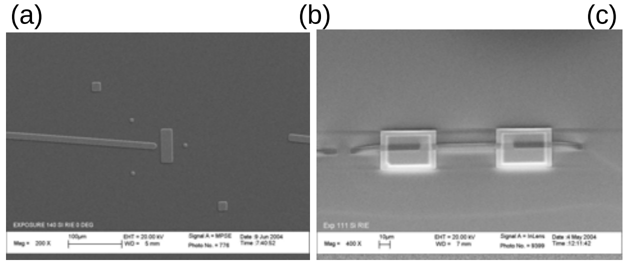


(a) (b)

Figure 6. (a) Dimensions of the unit cell. (b) The entire photonic crystal structure layout which contains 10 rows with 100 pillars per each row.



(a) (b) (c)



(d) (e)

Figure 7. SEM photomicrographs: (a) anisotropically dry etched triangular array of circular silicon pillars with diameters in the range of 500 nm ~ 2.5 μm; (b) close-up view; (c) a triangular array of circular silicon pillar embedded in a patterned polyimide; (d) angled silicon waveguide; (e) air suspended FPC.

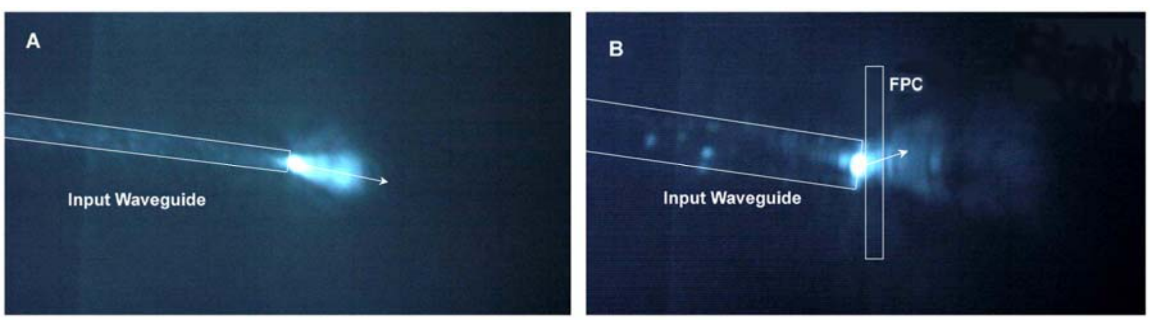


Figure 8. Collected light propagation images: (a) straight light propagation w/o PC; (b) giant negative refraction through the 2D slab Si/polymer PC.