Optically Actuated All Optical Mechanical Switch

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Photogeneration of electron-hole pairs in semiconductors results in mechanical strain. Photoinduced deflection is utilized to modulate light with wavelength 1.3 and 1.55 μm. This presentation discusses design, microfabrication, and results of the novel micro-switching device.

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As speeds in communications, sensing, and computation increase rapidly, fast switching mechanisms are essential. Since optical signal processing has distinct advantages over electromechanical or magnetic processing due to its reliability in harsh environments, optical switching techniques have received much attention for addressing these applications. Because of the complexity of optical switching mechanisms, often one must trade off one or more of the five basic parameters: throughput/rejection efficiency, actuation power, cost, speed, and size. Here we discuss a novel approach based on MEMS (micro-electro-mechanical-systems) for optical switching that could optimize all five parameters simultaneously. In addition, since this is an optically actuated optical switch, nonconductors can also be actuated, such as ultra-high resonant frequency diamond MEMS waveguides. With this approach, we can take advantage of photons over electrons due to the use of two-way conductors, cross conductors, ultra-high bandwidth and multi-wavelength operation. Even though there are many other optical switch designs, such as electrostatically driven flip-up[6] or rotary micro-mirrors[7], thermo-mechanically actuated micro-cantilever beams[2], and electromechanically actuated evanescent field couplers[1], this microdevice is unique for being an all-optical device.

Recently, we have observed[3] an opto-mechanical phenomenon that could have tremendous importance in optical switching. This switching mechanism is a micro-mechanical movement induced by the optical absorption of the waveguide material. Photons above the bandgap are absorbed in a semiconducting material, which generate electron-hole pairs. If enough electron-hole pairs are created and recombination is slow, the lattice parameter of the material changes, resulting in material strain. If the waveguide material is free to move (such as a severed micro-bridge), then the strain will alter the position of the waveguide material. This micro-mechanical movement can be used to switch a light beam traveling down the waveguide either as a modulator (on / off), or to redirect light coming from the end of the waveguide onto two or more different receiving channels (switch).

It is well known that absorption of photons by a semiconductor generates thermal and photoinduced strains, and the maximum deflection z_{max} due these strains is given by[4]

$$z_{\max} = \frac{(1-u)\cdot l^2}{t}\cdot\frac{de_g}{dP}\cdot\Delta n + \frac{3\cdot(1-u)\cdot l^2}{t}\cdot a\cdot\Delta T,$$

where n is Poisson's ratio, $de_g/\,dP$ is pressure dependence of the bandgap, Dn is the photogenerated excess charge carriers, a is the thermal expansion coefficient, l is the transverse length of the cantilever, t is the thickness, and DT is the changes in temperature. The first term in this equation is due to the photo-induced stresses, whereas the second term is due to the thermo-mechanical stresses. Since $de_g/\,dP$ can either be positive or negative, there can be a competing effect between photoinduced and thermal stresses. For a negative $de_g/\,dP$, the photoinduced stress will cause a contraction of the semiconductor crystal structure, whereas the positive values will tend to expand the crystal structure.

The rapid generation of excess charge carriers causes the photoinduced deflection that demonstrate itself substantially faster than the thermal deflection. For example, the photoinduced deflection of a severed silicon micro-bridge with l = 100µm, t = 0.5µm, w = 20µm, and a 30 nm Al layer on one side, exposed to near infrared photons from a diode laser with wavelength 780 nm reaches its maximum deflection value more significantly faster than the thermal response that was achieved with illumination with 1.3 µm photons.

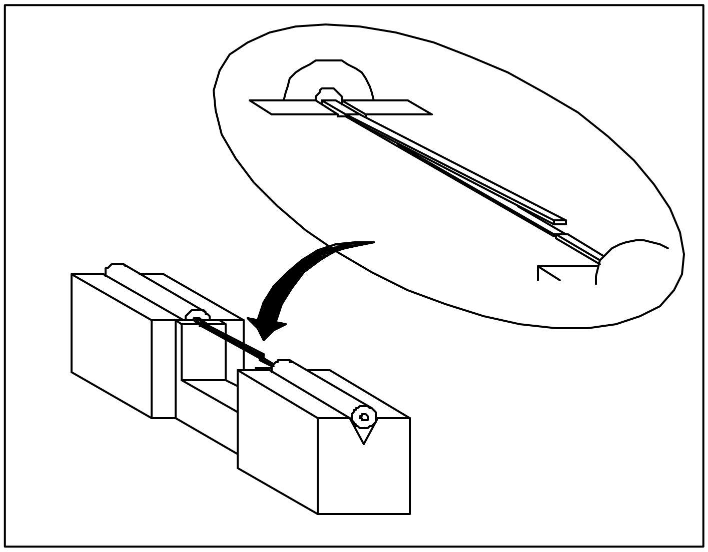

Figure 1 3-D representation of the optical switch. V-grooves are used to align input and output fibers. Single-mode cables are centered with the cross-sectional area of the silicon waveguides.

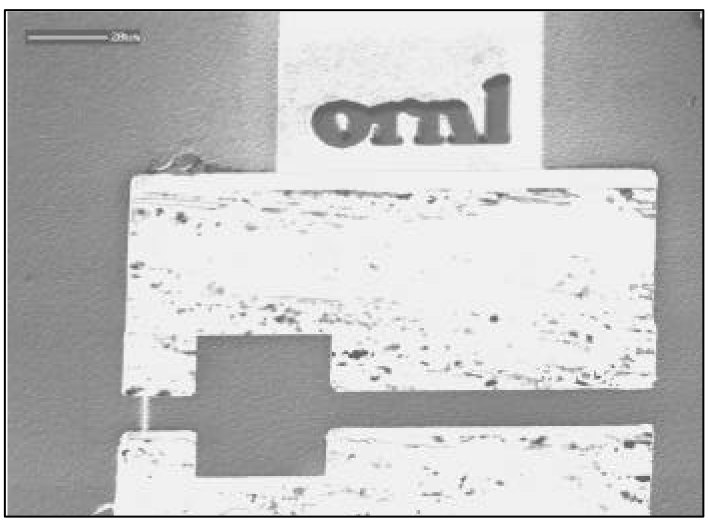

Figure 2 Scanning electron image of the micro-bridge waveguide. The gap where the waveguide is separated from the receiver end is approximately 1 µm. The rectangular area at the tip is designed to enhance the sensitivity for read-out and photoinduced power absorption for actuation purposes.

The photonic switch, as seen in Figure 1, is composed of input-output alignment V-grooves[5] at each end and a silicon microbridge waveguide that is severed for light modulation at one end. The V-grooves are designed to hold 125 µm diameter single-mode optical fiber centered with the cross-sectional area of the microbridge. Single-mode fibers with 5 to 7 µm core diameter are utilized to transmit light at 1.3 and 1.55µm wavelengths through the microbridge.

The micro-switch is actuated with an infrared diode laser at 850 and 524nm wavelengths, which is directed at the tip of the micro-cantilever perpendicular to the modulated signal direction. The rectangular area at the tip, as shown in Figure 2, is designed to enhance photoinduced power absorption of the infrared radiation excitation, which causes the micro-bridge waveguide to deflect. As seen in both Figure 1 and 2, the micro-bridge is severed to produce a sub-wavelength gap (>1µm).

During the development phase, we monitored deflection of the waveguide by optical means. The side opposite of the actuation laser was utilized to reflect a read-out laser diode beam at 635-nm wavelength. The reflection of the laser beam is then detected by a position sensitive photodiode to determine the deflection of the severed waveguide. Since the deflection of the microcantilever beam is proportional to the output current of the photodiode, bending of the switch is determined.

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