Microscale Cantilever Beam Resonators "Weigh" Individual Virus Particles

Nanotechnology researchers are pursuing the fabrication of a lab-on-a-chip device to detect biochemical entities such as airborne virus particles. As reported in the March 8 issue of *Applied Physics Letters*, A. Gupta and co-workers at Purdue University have taken a mechanical approach and fabricated an array of microscale resonant cantilever beams, which act as mass detectors. The frequency of oscillation of each cantilever is measured using a microscope scanning laser Doppler vibrometer under ambient conditions. The cantilevers are small enough that they do not require an external source, but are driven by thermal and ambient fluctuations. The researchers dispersed a solution of vaccinia virus particles (vaccinia is a member of the *Poxviridae* family and forms the basis for the smallpox vaccine) in deionized water over the cantilever array and allowed the particles to incubate for 30 min before drying the array. They showed that the attachment of a single vaccinia virus particle, with a mass of about 10 fg, shifts a 1.27 MHz resonant frequency by 5%. The researchers have demonstrated that the shift in the natural frequency is proportional to the effective number of virus particles on the beam, as expected from a mechanical analysis, by imaging the cantilevers with a scanning electron microscope and counting the number of virus particles attached.

The scientists started with *p*-type silicon-on-insulator wafers and photolithographically patterned and etched the arrays of 5-μm-long cantilevers in the silicon. The cantilevers are 1–2 μm wide and 20–30 nm thick. After protecting the cantilevers with an oxide etch-stop layer, the research team used a xenon difluoride

High-Speed Silicon Optical Modulator Developed

Silicon, the material of choice for electronics, has not seen wide consideration as an optical material for photonics. A key limitation has been the relatively low speed of silicon optical modulators compared with other materials such as III–V compounds and lithium niobate. Researchers from Intel, led by A. Liu, have now reported the fabrication of an all-Si optical modulator with a modulation bandwidth exceeding 1 GHz. This represents a nearly two orders of magnitude improvement over previous Si devices, which have modulation frequencies in the range of ~20 MHz. Liu and co-workers described their approach, based on a metal oxide semiconductor (MOS) capacitor structure embedded in a Si waveguide, in the February 12 issue of *Nature*.

In this device, the modulation of light for encoding data as changes in intensity is achieved by modulating the refractive index. In Si, this is achieved by the free-carrier dispersion effect; the introduction of free carriers results in absorption and also a change in the refractive index. The researchers used a MOS capacitor phase shifter for charge-density modulation that induces a phase shift in the optical mode. Their device consists of an *n*-type Si slab and a *p*-type doped polysilicon rib with a gate oxide layer sandwiched in between. The poly-Si was formed by chemical vapor deposition of amorphous Si and subsequent annealing under conditions that minimize grain-boundary formation. Aluminum contacts were deposited on the sides of the rib waveguide (see Figure). The modulators were fabricated in an existing Intel complementary MOS (CMOS) production facility, demonstrating the use of existing infrastructures for fabricating these and similar devices and indicating the potential ease of integration of optoelectronic components into CMOS microelectronics. Modeling and testing confirmed that this was a single-mode optical device at a wavelength of ~1.55 μm, which is widely used in optical-fiber communications.

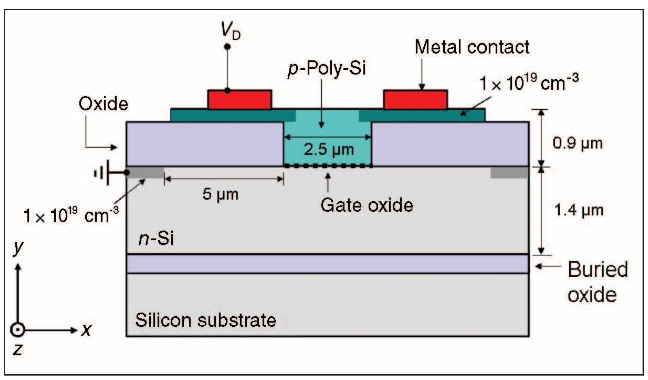

Figure. Schematic diagram shows the cross-sectional view of a metal oxide semiconductor capacitor waveguide phase shifter using silicon-on-insulator technology, where V_D is drive voltage and 1×10^{19} cm^{-3} is the doping density. (*Nature* ***427*** *[2004] p. 616.)*

To test the modulators, an asymmetrical Mach–Zehnder interferometer (MZI) was fabricated, with two identical MOS capacitor phase shifters in two arms of the MZI, to convert the phase modulation into an intensity modulation. The MZI had an optical path length difference of 16.7 μm between the two arms; Y junctions allowed for the splitting and recombination of the optical beams. The MZI had an on-chip insertion loss of 6.7 dB, a phase shifter length L of 1 cm, a $V_\pi L$ of 8 V cm (where V_π is the voltage required to produce a π phase shift), and an extinction ratio of >16 dB. Results demonstrated that the MZI modulator showed a roll-off frequency of >1 GHz by the induced phase shift. This modulation frequency is two orders of magnitude higher than that observed for traditional current-injection-based diode devices. The data transmission performance of the MZI modulator was tested using a digital pulse drive voltage. A pseudo-random electrical data input was used, and the corresponding MZI optical output was measured. The output optical signal faithfully reproduced the 1 Gbit/s electrical data stream.

The researchers said that the modulator performance could be further improved by replacing the polysilicon with single-crystal Si, which could reduce the on-chip insertion loss by ~5 dB. Work on this is currently under way. Reducing the waveguide dimensions and making the gate oxide thinner would also reduce the optical loss as well as device size. The implications of this study could be far-reaching. It has clearly catapulted Si into the research spotlight as a strong candidate material for photonic applications. In particular, since a strong fabrication infrastructure already exists for Si processing, it may be much easier to quickly incorporate Si into the photonics industry and rapidly achieve economies of scale similar to those found in the electronics industry. A low-cost silicon optical superchip could become a reality very soon.

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