Silicon Nanophotonic Add-Drop Filter Based on High-*Q* Square Resonant Cavities

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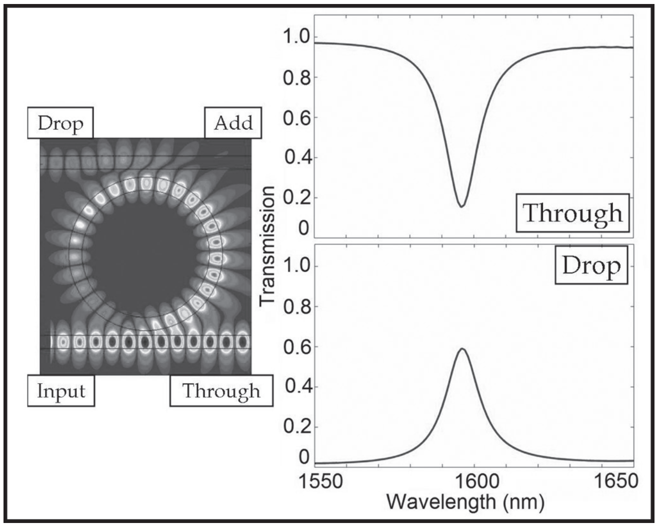

Figure 1: FDTD simulation field plot and modal power transmission for a microring resonator add-drop filter. (See full-color version on inside cover.)

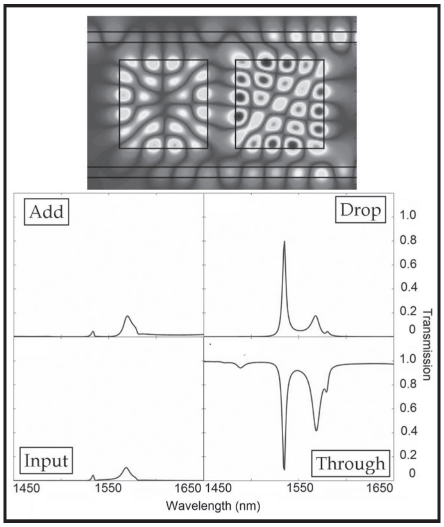

Figure 2: FDTD simulation field for a square cavity add-drop filter. (See full-color version on inside cover.)

OPTS

Abstract and Introduction:

Silicon nanophotonic devices can process optical signals analogously to the way in which electronic devices process electrical signals. They have applications in telecommunications and the potential to be integrated within computer chips. One key device in photonic circuits is the add-drop filter, which can be used for wavelength-division multiplexing. This filter is commonly implemented with a microring resonator placed in between two parallel waveguides. When light passes through the transmitting bus, the ring resonates at a certain wavelength, based on its geometry. This mode propagates around the ring and into the receiving waveguide. The modal power fraction of light transmitted from the input "port" to each of the output ports, i.e. waveguides' cross-sections, is of interest. Figure 1 shows the through and drop port responses of a microring add-drop filter. A similar response can be achieved with a two-square cavity geometry [1]. In this design, the optical excitation alternates back and forth between the two square cavities in time. This "push pull" behavior means that these standing-wave cavities channel light as does a traveling-wave ring resonator. The goal of this project was to fabricate a two-square cavity add-drop filter.

Procedure:

A silicon-on-insulator wafer was used to fabricate the photonic structures. The wafer consisted of 220 nm of silicon atop 3 μm of silicon dioxide. A 190 nm layer of hydrogen silsesquioxane (HSQ), a negative tone resist, was spun onto the wafer at 1000 RPM for one minute. The wafer was dried in a vacuum oven for five minutes to remove the HSQ's solvent. Electron-beam lithography (EBL) was performed using a JEOL 5910 LV scanning electron microscope (SEM) that interfaces with a computer program to write the desired pattern in a single writing field. The design was created in DesignCAD based on the results of two-dimensional finite-difference time-domain (FDTD) simulations.

Various electron-beam dosages were given for the different structures in the design. The sample was then developed in tetramethyl ammonium hydroxide (TMAH) heated in a 40°C water bath and then in a solution of 1:9 TMAH:water, also heated to 40°C in a water bath.

Process Development:

The HSQ development procedure was changed during this project to fabricate high-contrast structures. Previously, the HSQ was pre-baked at 90°C before EBL to dry the solvent from the solution. After EBL, the sample was developed in the two solutions of TMAH at room temperature. However, polymer chains within the HSQ cross-link when it is exposed to elevated temperatures [2], producing areas of partially developed HSQ near exposed areas. The procedure was improved by drying the solvent at room temperature and development at 40°C. Heating during development removed partially developed HSQ caused by electron beam backscattering.

Another challenge in fabrication were proximity effects from EBL, which are caused by backscattering of secondary electrons that bombard the sample. The proximity effects were mitigated by varying exposure dosages and by adding sidewalls near the gratings to create approximately "even loading" (average dosage) across structures. However, the equipment seemed to give inconsistent exposures, and exact numbers were not calibrated for the electron-beam dosage.

Results:

A grating-to-grating connection via a waveguide was fabricated to obtain a baseline test for the optical fiber-to-fiber power loss. The device's gratings were designed to couple 1550 nm wavelength light into the waveguide. The laser's wavelength was swept from 1495-1640 nm, and the power transmission along this range is shown in Figure 3. Transmission of about -50 dB was achieved, but high coupling loss remains. The response shows a deep modulation with a 21 nm wavelength period, which corresponds to a free spectral range (FSR) of 2.6THz. This could be the result of coupling between the fundamental and third modes within the taper, coupling from a transverse electric (TE) to a transverse magnetic (TM) mode, or mode conversion from TE to TM in the waveguide bends. There is also a secondary ripple with a 0.5 nm period, which could be caused by a reflection between the input and output terminals, with sufficient resonant delay in reflection by the grating couplers.

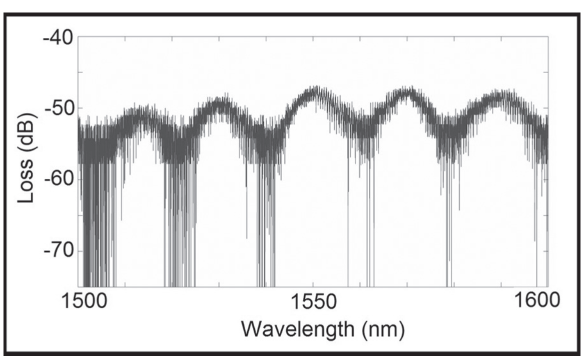

Figure 3: Optical response of the grating-to-grating connection.

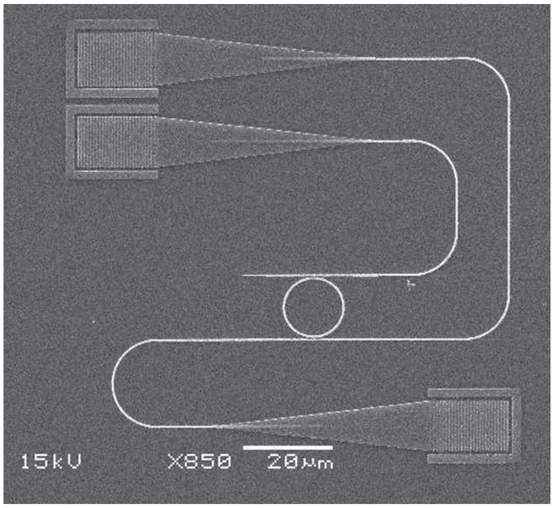

Figure 4: SEM of fabrication including a microring resonator.

A microring resonator was fabricated for testing, because its response is well known [3] (see Figure 4). This device gave no meaningful optical response. SEM images showed inconsistent structure heights, which would have caused high power loss if light had been coupled into the device.

Conclusions:

A photonic fiber-to-fiber connection, comprising two fiber-to-chip grating couplers and a silicon waveguide connection on a silicon chip was demonstrated.

To complete the sought goal, the next step would be to fine tune the fabrication process until a circuit with a working microring resonator add-drop filter is produced. Then, a three-dimensional mode solver software would be used to find the square resonant cavities' dimensions with a high quality factor at a decided wavelength of light. The two-square add-drop filter would be tested optically, and these measurements would be compared with the theoretical response produced by FDTD simulation.

Acknowledgements:

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References:

[1] Manolatou, C., et al. "Coupling of Modes Analysis of Resonant Channel Add-Drop Filters." IEEE Journal of Quantum Electronics, Vol. 35, No. 9, September 1999: 1322-1332.

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