

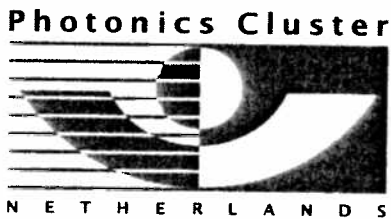


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Retroreflective optical marker chips for simultaneous identification and localization

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We demonstrate an optical marker in SOI that enables simultaneous identification and localization of objects. The most important chip requirement - retroreflectivity - is realized by a large number of equally designed reflective ring resonator circuits, but operating at different angles of the incident light. An infrared camera captures the marker response during flood exposure by a tunable infrared laser. Interference problems are solved by coating the chip with a planarized gold layer. A oxide compaction method is examined to correct for variations in the resonance frequency of the rings due to waferscale fabrication.

Introduction

Current marker techniques, such as barcodes and RFID, do not allow efficient localization of the marked objects. Localization with barcodes requires complex image processing, while RFID localization will have a very poor resolution due to the large wavelength of the radiowaves. This limits the use of these techniques in the automation industry. The use of infrared light can overcome this problem. Although it requires the objects to be in line of sight (like with barcodes), the spatial resolution will improve drastically.

The system we propose consists of a tunable infrared light source, an infrared camera and a scene with several marked objects. The infrared source lights the entire scene. The marker-chips capture the source light and send a filtered version back in the direction of the source. The filter operation retains one or several distinct peaks at specific wavelengths. This spectrum serves as the identification code of the marker. By positioning an infrared camera close to the light source, the response of the marker-chips can be captured. The light source sweeps a certain range of wavelengths, while the camera makes an image for every wavelength. The images will show a bright spot when one of the markers is at resonance. The corresponding wavelengths identify the object and the coordinates of the spots in the image can locate the object within the scene.

The marker design

To obtain a miniaturizable marker, we use a silicon-on-insulator (SOI) chip [1]. Because of the high refractive index contrast between core and cladding, light can be bent over just a few micrometer. Ring resonators, which will perform the filter operation, can therefore be spectacularly miniaturized [2]. Because ring resonators are passive filters, a high coupling efficiency into and out of the chip is needed. Efficient coupling will be achieved by

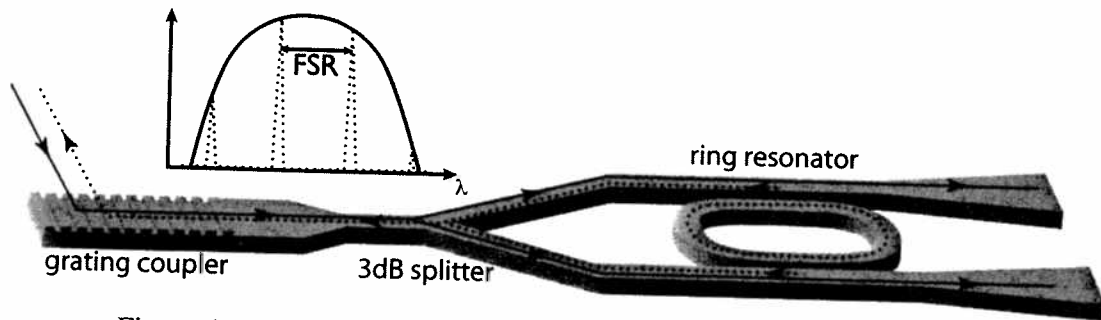


Figure 1: Schematic representation of the retroreflective substructure.

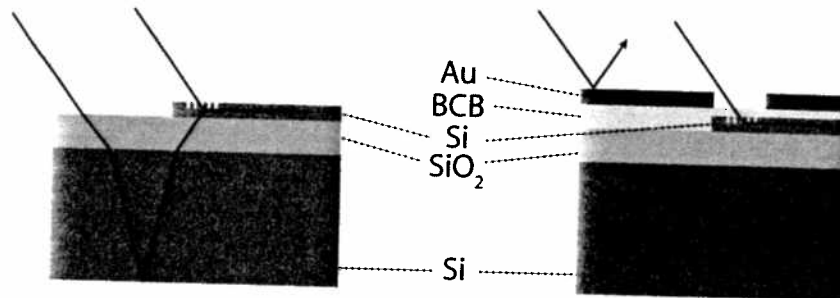


Figure 2: Interference due to flood exposure is eliminated with a gold toplayer.

focusing grating couplers, which have already been studied extensively within the photonics research group [3] and reach efficiencies of about 30%. For a given wavelength, these periodic gratings operate at a fixed angle, corresponding to the Bragg condition. The entire system relies on the retroreflectivity of the marker-chips. By coupling the filtered light back to the same grating coupler, the light is sent back at the same angle as it was received, i.e. retroreflective. However, creating a retroreflective chip for any arbitrary direction of the incident light is less straightforward. This problem is solved by combining 120 retroreflective substructures that operate at a slightly different fixed angle. Each of these substructures - depicted in figure 1 - couples the source light into and out of the chip through the same grating coupler, hence the marker's retroreflectivity.

Post-processing to avoid interference problems

Flood exposure introduces interference problems, because light can penetrate the chip, reflect at the bottom of the substrate and enter the grating couplers. The directly coupled light will interfere with the light entering from the substrate (see figure 2-left). From the optical path difference the period of interference can be determined. This corresponds very well to the measured interference pattern. To eliminate this effect, the entire chip - with exception of the grating couplers - is covered with a highly reflective layer (Au) by sputtering and lift-off. Because of the good step coverage, structural edges reflect a lot of light, and saturate the camera. Therefore, an intermediate BCB-layer is spin-coated between the SOI-chip and the layer of gold to obtain a very good planarization (see figure 2-right). The interference pattern disappears from the measurements which proves the effectiveness of the $0.1 \mu\text{m}$ thick planarized gold layer.

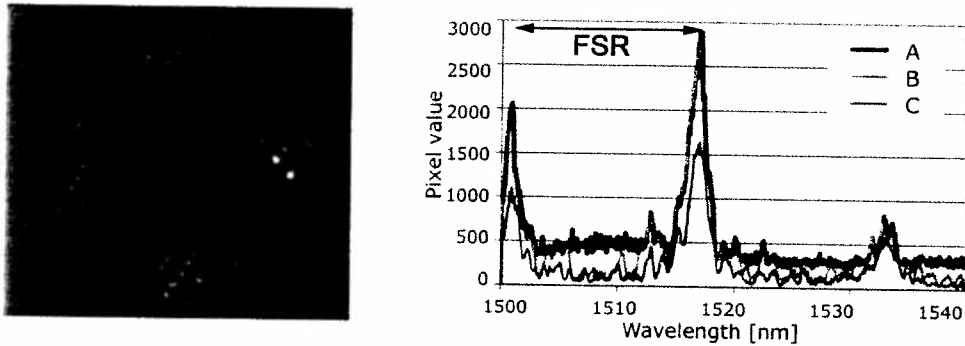


Figure 3: Left: camera-image of chip under flood exposure at 1517 nm. Right: Response of (A) the whole chip, (B) brightest spot and (C) second bright spot.

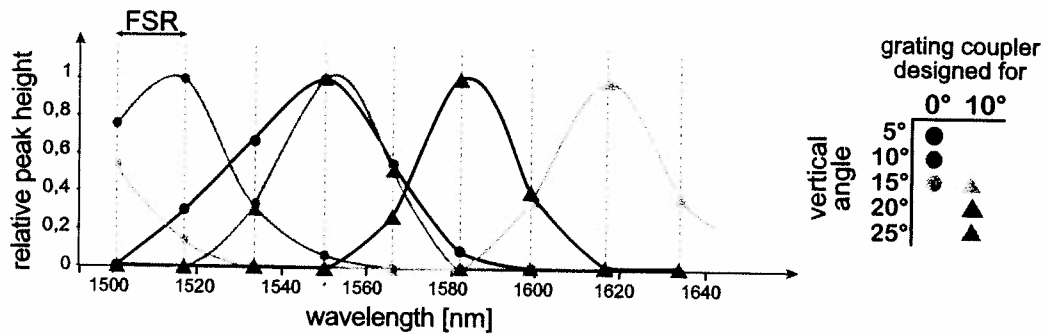


Figure 4: Normalized grating bandwidth (full lines) estimated from peak heights (dots and triangles) measured at five different vertical angles with two different grating couplers.

Measurements

To obtain the ideal set-up in which the light source is on the axis chip-camera, a fiber is cleaved at a certain angle, so it can be placed almost normal to that axis. Because the tip of the fiber is far out of focus it doesn't disturb the measurements.

Camera images (figure 3) show that some light still reflects at the gold edges near the grating couplers. Fortunately, the intensity of the retroreflected filtered light dominates for most incident angles. The graph was obtained by plotting the maximum pixel values over (A) the whole chip, (B) the brightest spot and (C) the second bright spot. In this marker, only one wavelength is retained per free spectral range (FSR). Notice that (A) and (B) coincide at the resonance frequency, showing that the background noise doesn't overpower the light coupling out of the grating couplers.

The two responsive grating couplers in this example are designed for different orientations, showing an overlap in their response. A continuous response is therefore ensured when rotating the chip. Changing the vertical angle of the chip by tilting it, causes a wavelength shift. This shift spreads the response of the marker over multiple free spectral ranges. In figure 4 the peak heights are used to estimate the bandwidth and center wavelength of the grating couplers at five different vertical angles. There is a small overlap at 15° between the grating couplers which are designed for 0° and 10°. This means the identity of the marker can be determined at all angles, provided a sufficiently large frequency range is swept by the source.

The next generation IRID markers

In a more efficient arrangement using 2D grating couplers [4], a rough estimation shows that a total number of 144 grating couplers is sufficient to ensure a continuous response within one FSR. The use of bent-coupled ring resonators is suggested to increase the FSR. Furthermore, a highly absorbing top layer would enable vertical measurements and decrease unwanted reflections even further.

Filter adjusting

As can be understood from this concept, for each different angle of the incident light a different substructure will respond. The accuracy of the marker response is thus limited by the variations in the filter response. Especially in a high contrast system like SOI, small variations in the critical dimensions of the filters can lead to unwanted variations in the filter response. Therefore, a mechanism based on the compaction of silica, is explored to adjust the resonance frequency of the ring resonators.

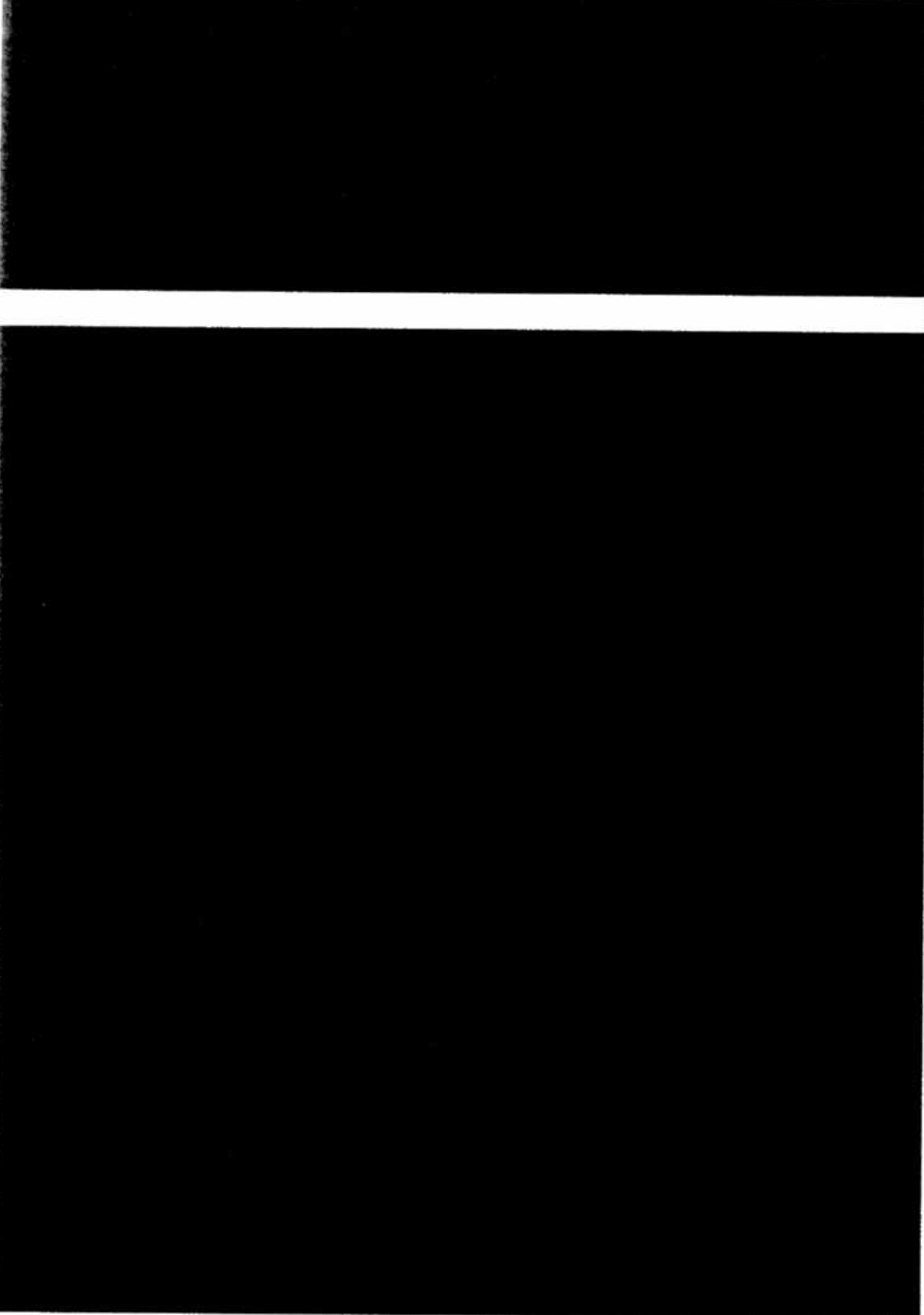
Electron impact with electrons of low energies (a few keV) will result in ionization induced compaction of the silica surrounding the ring resonators. This induces tensile stress in the ring which causes a red shift in its resonance frequency [6]. We used a scanning electron microscope at high magnification to irradiate the rings in a controlled manner. The longer the irradiation time, the longer the expected frequency shift. By taking into account the shift of a reference ring, effects such as temperature changes were ruled out. A net red wavelength shift up to 3 nm was measured after irradiation with 2 keV electrons. To predict the exact shift a series of compaction experiments are performed. Problems with reproducibility occur, probably due to the attraction of dust due to charging. To obtain reproducible results, new measurements will be performed inside a cleanroom.

Conclusions

A new marker concept was presented, together with the very first marker design. The chips were post-processed to disable interference and direct reflections. Measurements prove the functioning of the optical marker, although its response is spread over multiple FSR's. Suggestions are made to optimize the current design and keep the response within one FSR. To obtain an angle-independent response, a compaction mechanism was investigated to adjust the frequency of the ring resonators.

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