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Enhanced 2D Beam scanning: optical-Phase-array on piezo-cantilever

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Abstract—This work reports the development of an enhanced 2D beam scanning by combining 200 nm silicon (Si) photonics and 200 nm Si MEMS technologies. It demonstrates the fusion of an active photonic beam-steering circuit within a piezoelectrically actuated micro-cantilever. Operating at a wavelength of 905 nm, the optical phased array (OPA) enables beam scanning up to 17° in one dimension. Simultaneously, the circuit's inclination, in a second dimension, can be independently adjusted over a range of up to 40° via the piezoelectric actuator. This paper will focus on the technological process that combines photonics and piezoelectric materials, as well as the possibility of tailoring the cantilever resonance frequencies via the dimensional parameters, to suit various target applications.

Keywords—Solid-state 2D beam scanning, Optical phase array (OPA), Piezoelectric actuator, PZT

Three-dimensional sensing is indispensable for enabling machines to navigate and engage with intricate, changing environments. Solid-state beam scanning devices are pivotal in meeting demanding system specifications of sensing range, resolution, refresh rate, and cost. Integrated OPAs, leveraging CMOS technology, hold promise as a solution [1]. By precisely controlling the phase of light from a large number of closely spaced emitters, it is possible to scan a low divergence beam over a wide field of view at high frequencies. Numerous feasibility demonstrations using silicon and/or silicon nitride photonics have been presented over the last decade. In a 1D OPA, adjusting the voltages on the phase modulators orients the output beam along a first axis. Therefore, to scan the beam along both axes, this 1D OPA must be used in conjunction with a second physical mechanism, unrelated to the phased array. The most widely used method is based on the wavelength dependence of the emission angle of the diffraction grating used to extract the light from each waveguide [2]. However, this relies on costly widely tunable laser source. As shown in Fig. 1, we have developed a new approach based on a 1D-OPA beam, designed to operate at $\lambda = 905$ nm, integrated into a Lead Zirconate Titanate (PZT) piezoelectric based cantilever, allowing 2D beam scanning [3]. Using this device, fabricated entirely on 200 nm Si wafer, we demonstrate in Fig. 2 continuous scanning over 17° from a 1D-OPA.

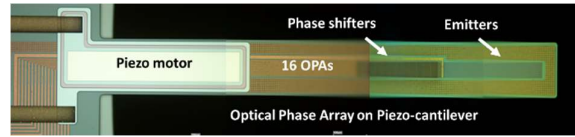


Fig. 1. Top view of the optical-Phase-Array on piezo-cantilever fabricated devices

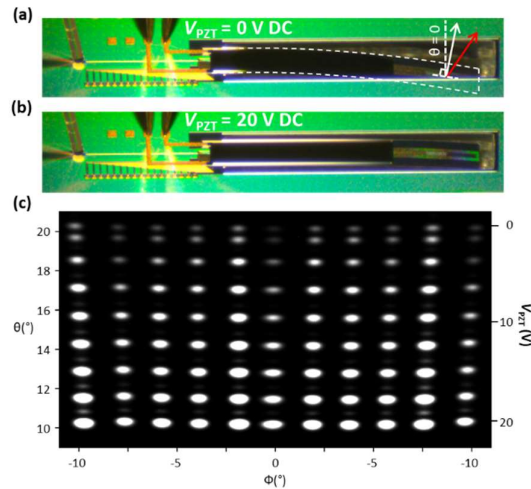


Fig. 2. 2D beam steering with quasi-static driving model ($V_{max}=20V$)

Simultaneously, we achieve beam scanning over an angle $\Delta\theta = 10^\circ$ with a maximum applied PZT DC voltage of 20 V, and up to 40° at the cantilever resonance frequency of 1.52 kHz.

The piezoelectric material is integrated onto a silicon substrate using a sol-gel deposition process, requiring a crystallization temperature exceeding $500^\circ C$, typically $700^\circ C$. However, such high-temperature annealing poses challenges to the integrity of the photonic component, especially the metallic parts. Hence, the adopted technological approach involves film transfer [4]. Here, PZT is deposited and crystallized on a donor substrate, then transferred to a host substrate with pre-fabricated photonic components. The technique is illustrated below and depicted in Fig. 3.

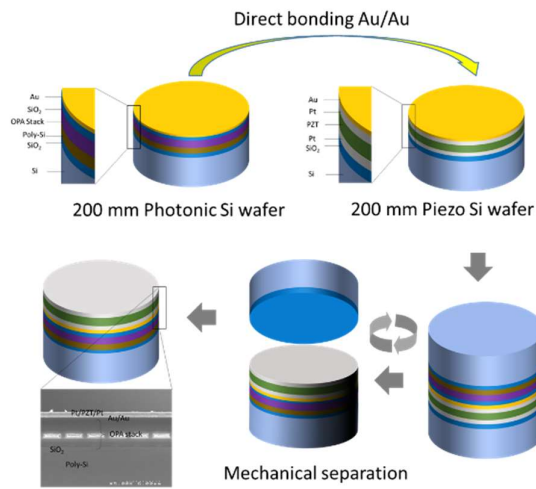


Fig. 3. PZT transfer process using 200 mm Si substrates

At the end of the process, 1D-OPAs mounted on piezoelectrically driven cantilevers, nearly 2.9 mm long, 400 μm wide, and approximately 5 μm thick, were fabricated. This technological process ensures the performance of PZT, with maximum piezoelectric coefficient d_{31} around 130 pm/V , as shown in Fig. 4.

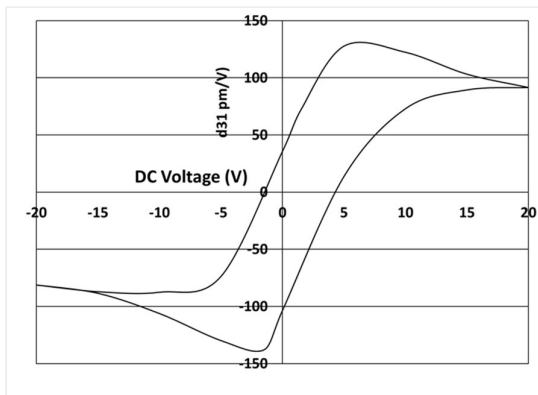


Fig. 4. Transverse piezoelectric coefficient $d_{31}(\text{V})$ of transferred PZT

This paper also presents the possibility of modulating the resonance frequencies of the cantilever by modifying its dimensional parameters, mainly its length and thickness. Fig. 5 shows a very good correlation between the experimental measurements of the first two resonant frequencies and the simulation results.

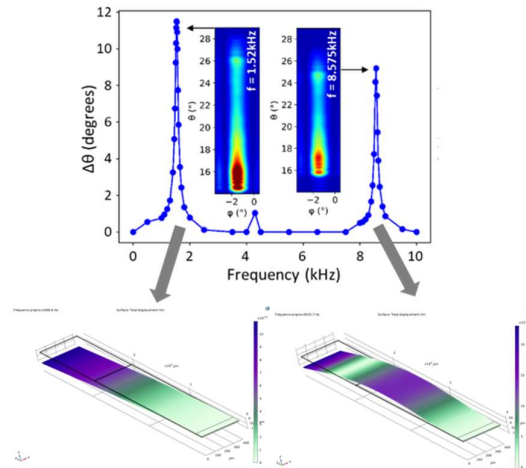


Fig. 5. Amplitude of the beam displacement as a function of the signal frequency (with $V_{\text{max}}=4\text{V}$) and comparison with COMSOL modeling (two first eigenmodes of the cantilever)

In the future, this will make it possible to adjust the resonance frequency to suit specific target applications.

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