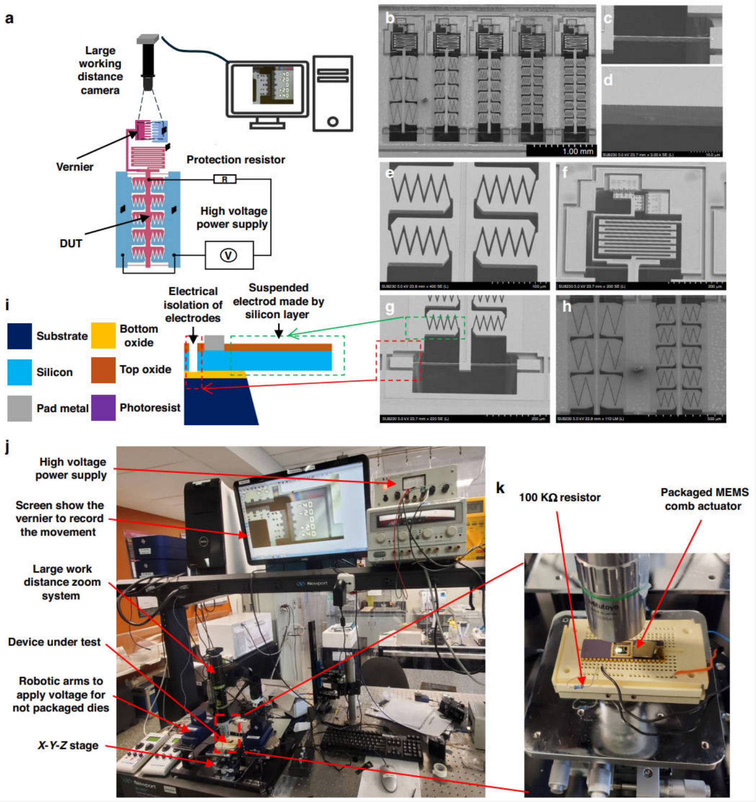
Angled micro-actuators boost force and range for next-gen silicon photonics

GA, UNITED STATES, February 19, 2026 /EINPresswire.com/ -- This study introduces a newly optimized triangular-finger electrostatic comb-drive actuator designed to significantly enhance force intensity and travel range within a compact footprint. By refining finger geometry, arm width, and electrode configuration, the research demonstrates how angled electrodes dramatically increase effective overlap and force generation without enlarging device size. The optimized design achieves over 200 mN/m² force intensity while maintaining stable travel of approximately 6 μm, meeting the stringent performance needs of beam-steering and tunable photonic systems. Through combined analytical modeling, finite element method (FEM) simulations, and fabrication-rule-guided constraints, the study establishes a practical and manufacturable strategy for next-generation micro-electro-mechanical systems (MEMS) actuators that support high-force, low-power operation in advanced silicon photonic circuits.



Experimental Setup and SEM Characterization of MEMS Triangular Comb Drive Actuators.

Silicon photonic systems rely increasingly on micro-electro-mechanical systems (MEMS) actuators to provide precise beam steering, wavelength tuning, and optical switching. These applications demand actuators capable of producing high force, wide travel ranges, and rapid response, all while fitting into tightly constrained chip-scale footprints. Traditional rectangular comb-drive actuators often struggle to simultaneously meet requirements for force density, displacement, and fabrication reliability, especially within modern SOI-based photonic platforms. Furthermore, nonlinear stiffness, pull-in instability, and footprint expansion limit their broader applicability. Addressing these challenges requires actuator designs that maximize electrostatic efficiency while preserving manufacturability and structural stability. Due to these issues, deeper research is needed to redesign comb-drive geometry for high-performance photonic integration.

Researchers from Concordia University reported (DOI: 10.1038/s41378-025-00906-6) in October 2025 in Microsystems & Nanoengineering a new triangular-finger electrostatic comb-drive actuator engineered for high-force, compact silicon photonic devices. Their study analyzes how angled electrode geometry, optimized arm width, and controlled traveling range can dramatically improve force intensity without increasing the device footprint. Using analytical modeling, finite element method (FEM) simulations, and fabrication-constrained design rules, the team demonstrates a manufacturable actuator that achieves strong force output, stable displacement, and minimal lateral instability, offering an advanced solution for beam steering and tunable photonic components.

The study systematically investigates how triangular comb-finger geometry enhances actuator performance by reshaping the electrostatic force distribution. By modeling each angled finger flank as an inclined parallel-plate capacitor, the researchers derive force equations showing exponential force gains as finger angles decrease toward 10°, the minimum manufacturable angle. Analytical models reveal that reduced finger pitch increases effective electrode overlap until limited by fingertip non-overlap. Parametric analyses (Fig. 3) show how finger angle, travel range, and arm width collectively define the optimal force density.

A major contribution is the rigorous optimization of arm width to prevent lateral pull-in triggered by arm bending. Through mechanical modeling and nonlinear stiffness analysis (Fig. 2), the authors determine a 19.5 μm arm width maintains safe electrode gaps with only 7% travel-range sacrifice. This ensures stability even as inter-finger gaps shrink from ~3.5 μm to ~2 μm during actuation.

FEM simulations validate the analytical trends: force intensity increases with finger number, peaking near 6 fingers per arm under fixed footprint constraints. Electric-field norm visualizations (Fig. 4) show strong field enhancement for intermediate configurations before tapering at high finger counts. Across analytical and numerical models, the optimized actuator achieves over 200 mN/m² force intensity and ~6 μm travel range—meeting the requirements of continuous-waveguide beam steering and tunable optical filters.

According to the authors, the triangular-finger geometry marks a significant shift in MEMS actuator design for silicon photonics. They emphasize that the balance of manufacturability, force density, and stable displacement has long been a bottleneck in integrating high-performance actuators into compact photonic circuits. By incorporating fabrication-aware constraints, nonlinear stiffness modeling, and electrostatic optimization, the new design framework provides a reliable pathway for producing strong, predictable actuation. The team highlights that the actuator's linear displacement behavior under specific configurations is especially valuable for precise optical tuning in advanced photonic networks.

The optimized triangular-finger comb drive offers broad potential across silicon photonics, including beam steering in LiDAR-on-chip systems, tunable lasers, variable optical attenuators, and wavelength-selective switches. Its strong force density and compact footprint allow integration into dense PIC layouts without sacrificing performance. The manufacturable 10 μm SOI-compatible design ensures that photonic foundries can adopt the actuator without modifying existing process flows. Beyond optics, the design principles may translate to other MEMS domains requiring high-force, small-footprint actuation. The findings establish a clear roadmap for next-generation MEMS devices that combine efficiency, reliability, and fabrication realism.

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