Large-aperture MEMS modulator paves way for high-speed, energy-efficient optical communication systems

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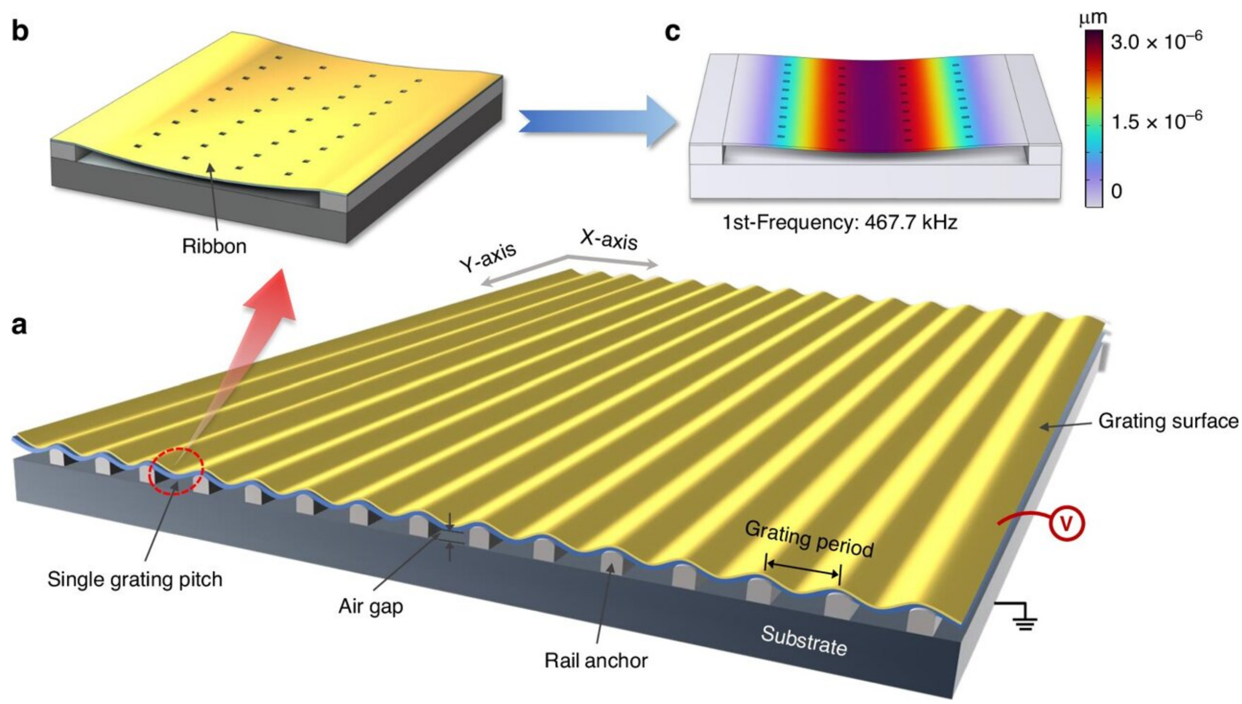

Schematic diagram of the proposed MEMS grating modulator. Credit: *Microsystems & Nanoengineering* (2025). DOI: 10.1038/s41378-025-00894-7

Microelectromechanical system (MEMS) optical modulators are crucial in next-generation technologies such as free-space optical communication and LiDAR, but existing designs struggle with balancing aperture size, efficiency, and speed.

Traditional micromirror-based modulators often operate at low frequencies, while grating modulators face bending deformations and suboptimal optical efficiency. Large apertures necessary for high-power systems have been hindered by mechanical constraints.

Based on these challenges, there is a pressing need for scalable, high-efficiency modulators to support the evolution of optical communication systems.

In an article published in *Microsystems & Nanoengineering*, researchers from Northwestern Polytechnical University introduced the innovative MEMS grating modulator featuring a tunable sinusoidal grating. This device achieves a large aperture of 30 × 30 mm, a remarkable 90% optical efficiency, and ultrafast response time approaching to 1.1 μs.

The device is designed to support high-speed modulation across a wide wavelength range (635–1,700 nm), offering promising solutions to challenges in high-speed, energy-efficient optical systems.

The modulator's key innovation lies in its broadside-constrained continuous ribbons, which prevent bending deformations and allow scalable aperture expansion without compromising the resonant frequency of about 460.0 kHz. The sinusoidal grating design maximizes fill factor (96.6%) and diffraction efficiency, achieving a 20 dB extinction ratio and 98% modulation contrast @100kHz.

Through-hole arrays on the grating surface optimize air damping, resulting in a critically damped response with no residual oscillations. Experimental results demonstrated full modulation with a contrast ratio above 95% @ 250 kHz, effective performance across the visible and near-infrared spectrum (±30° field of view), and reliable fabrication using a two-mask SOI process.

These innovations overcome traditional trade-offs between aperture size, efficiency, and speed, setting a new benchmark for MEMS optical modulators.

Dr. Yongqian Li, corresponding author of the study, highlighted the device's potential: "By combining scalable aperture design with unparalleled optical efficiency, this modulator opens up new possibilities for high-power, high-speed applications, from LiDAR to next-generation communication networks. The elimination of micromirrors reduces complexity and cost, making this technology scalable for widespread adoption."

The large aperture and high efficiency of the modulator make it ideal for free-space optical communication, ensuring long-distance signal integrity. Its rapid response time is well-suited for LiDAR and adaptive optics applications, while polarization independence adds versatility.

Future versions could enable multichannel beam shaping or integration with quantum communication systems. This innovation accelerates the development of energy-efficient, high-bandwidth networks, with broad applications in aerospace and telecommunications.

More information: Datai Hui et al, A MEMS grating modulator with a tunable sinusoidal grating for large-scale extendable apertures, *Microsystems & Nanoengineering* (2025). DOI: 10.1038/s41378-025-00894-7

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