Optical Multi-beam Steering using Integrated Acousto-Optic Arrays

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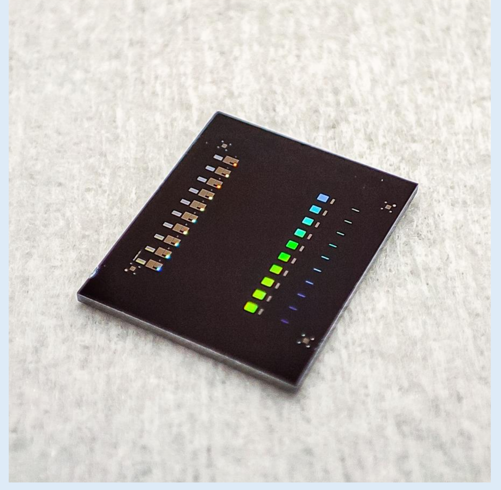
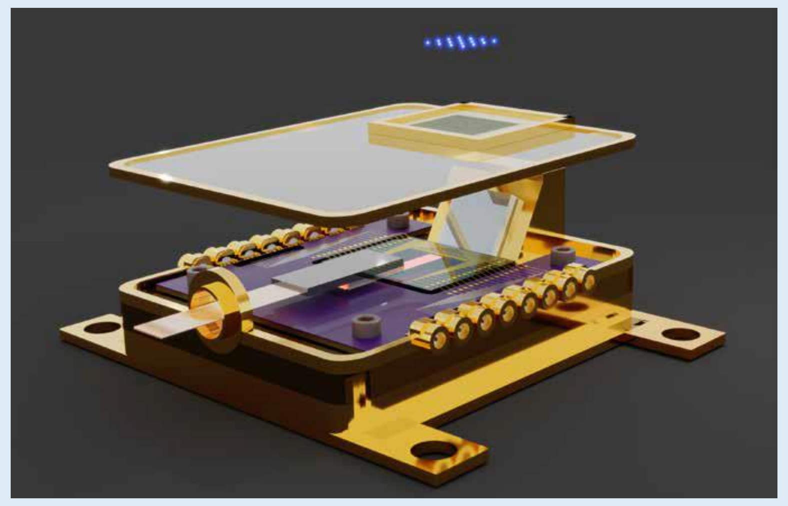
Introduction

- Acousto-optic devices have played a critical role in controlling optically addressed qubits such as neutral atoms and trapped ions.
- Acoustic waves propagate in the material generate moving phase masks, coherently shaping and modulating the light.
- Integrated acousto-optic array enables on-chip scalable multi-beam steering engine.



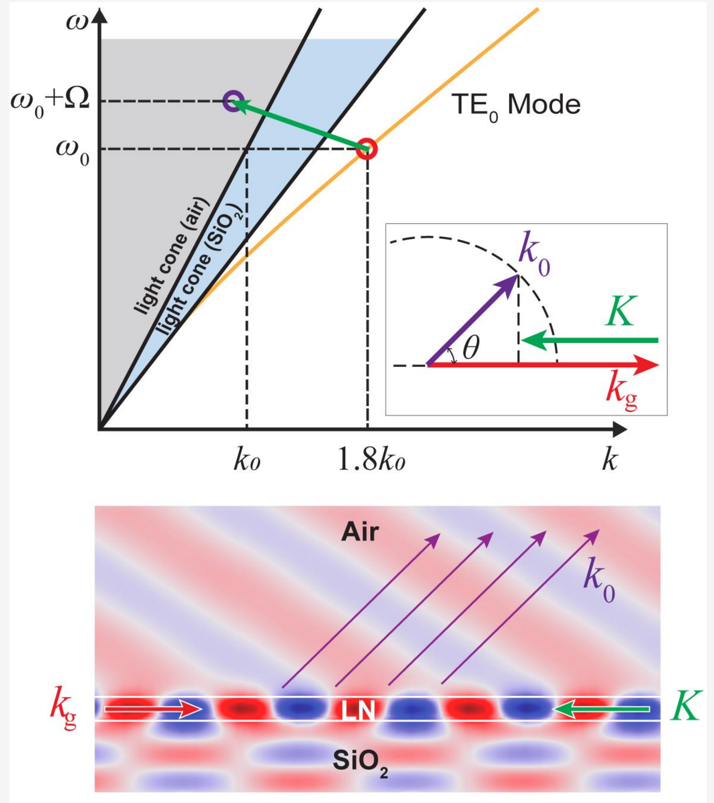


Acousto-optic beam steering (AOBS) Principles

- The lithium niobate on insulator (LNOI) substrate is used for the AOBS. The thin-film LN layer works as planar waveguide that confine both acoustic and optical modes, which enhances the AO scattering efficiency.
- Acoustic waves propagating in a material mechanically undulate its refractive index and thus provide a dynamically tunable index grating.
- The phase-matching condition determines the frequency-angular relation:

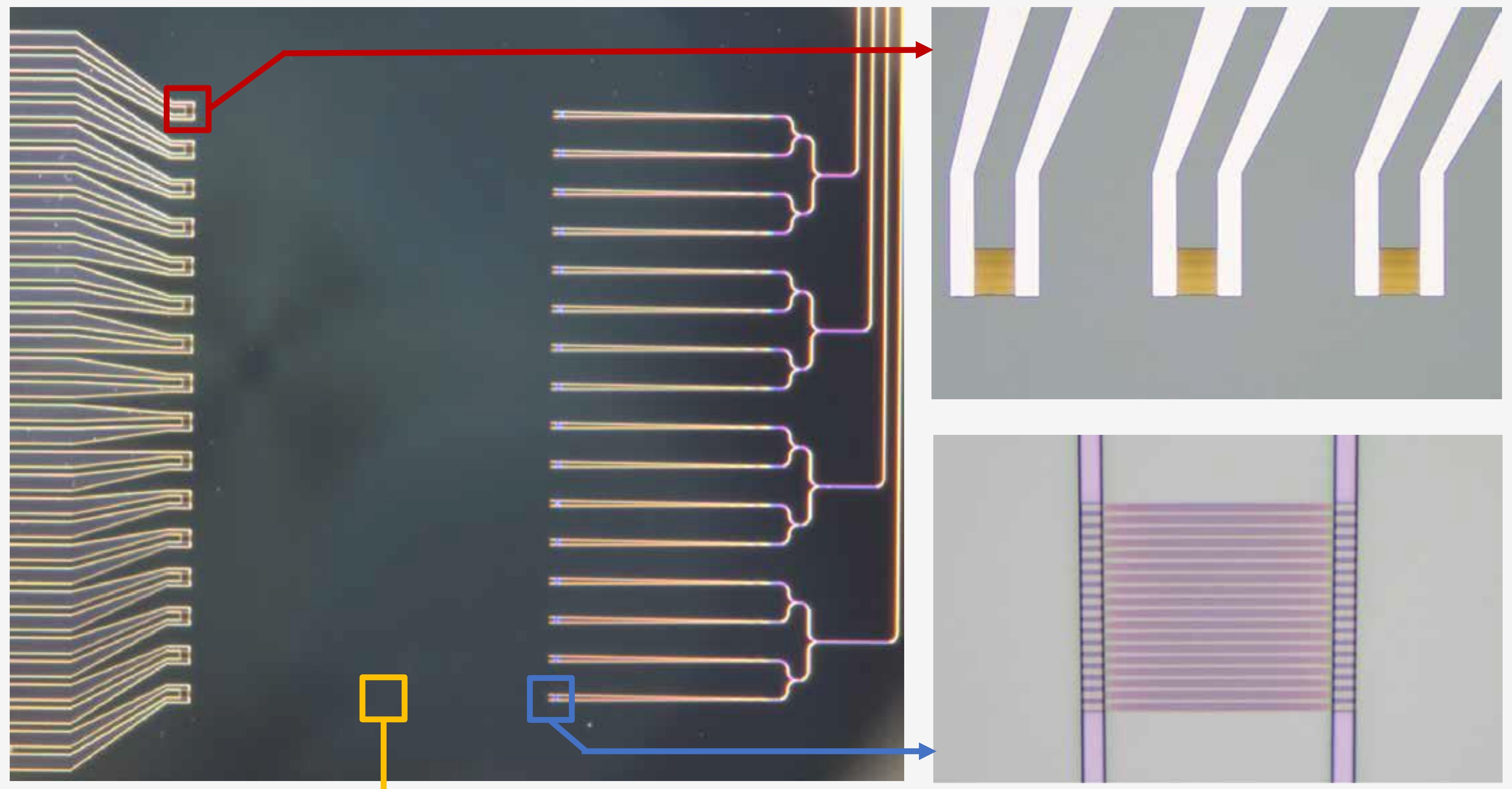
$$\cos(\theta) = \frac{k_g - K}{k_0} = n_e - \frac{c}{\omega_0 v}\Omega$$

- The scattered light frequency is up-shifted by the acoustic frequency Ω.



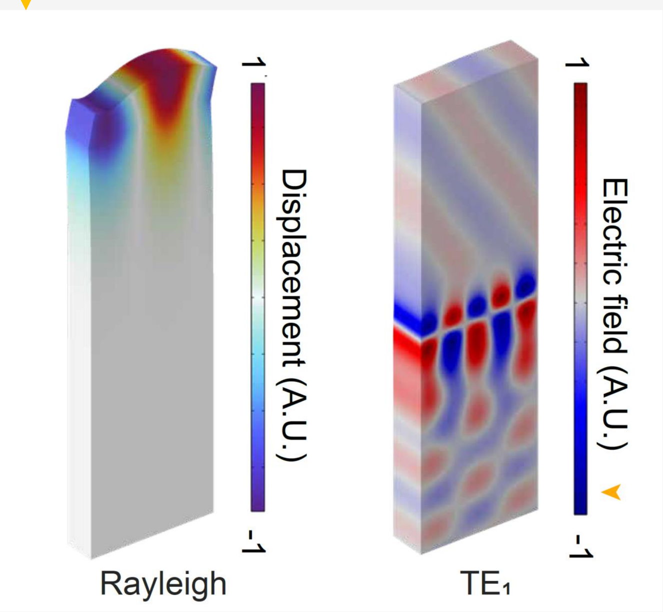
Device Design

- Optical: Light is coupled to the waveguides and routed to different acousto-optic (AO) channels.
- Acoustic: Surface acoustic waves are piezoelectrically generated by interdigital transducers (IDTs), which are wirebonded to an RF PCB and driven by an FPGA.
- Light in each AO channel is steered along horizontal axis (H-axis) by acoustic waves. Beams from different AO channels are collimated to different angles in vertical axis (V-axis) by a cylindrical lens.



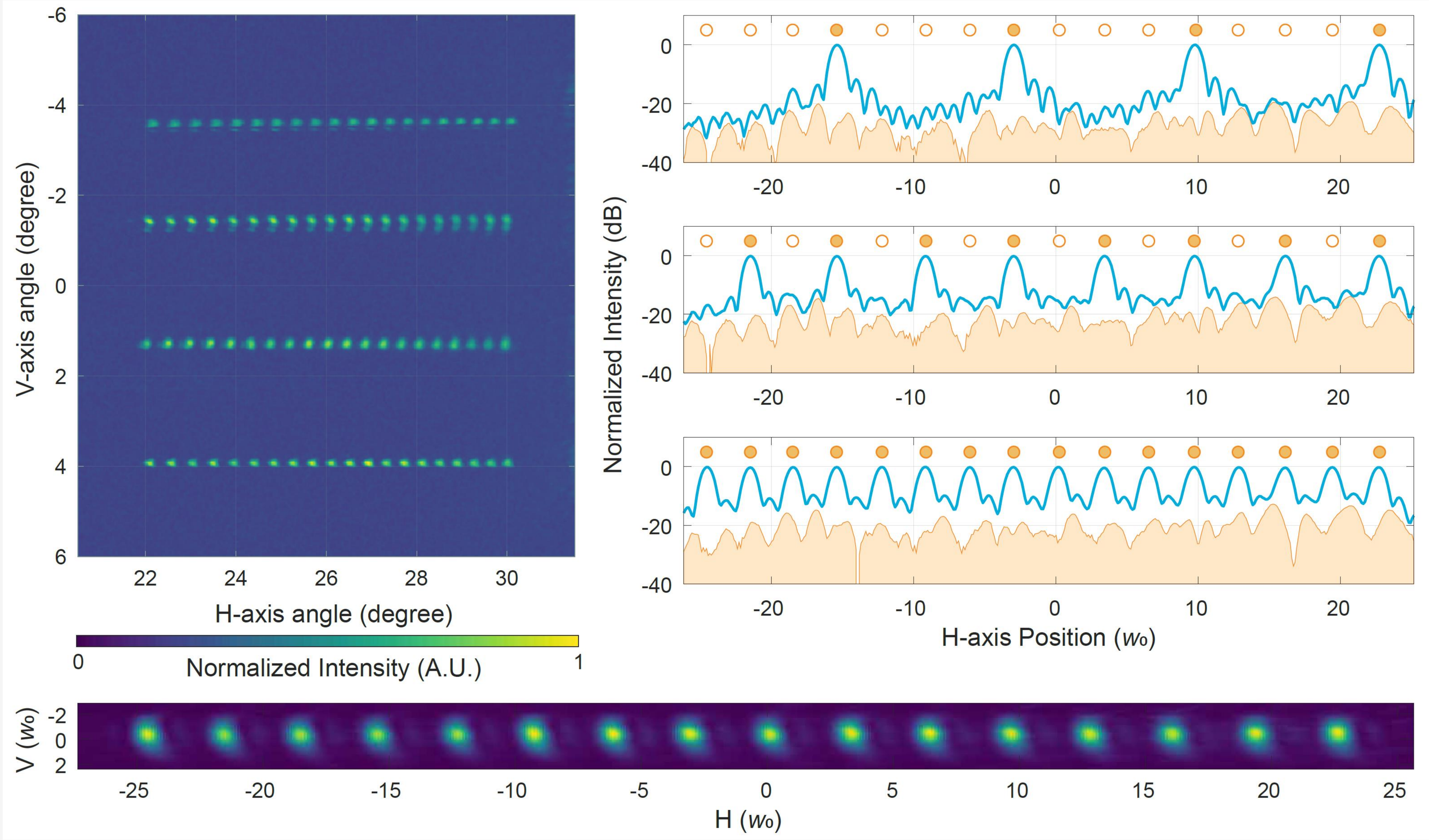
Simulation

- Acoustic Rayleigh mode: Out-of-plane displacements enable strong acousto-optics interaction
- Optical TE1 mode: Concentrates electric field near the lithium niobate – air interface to enhance acousto-optics interaction

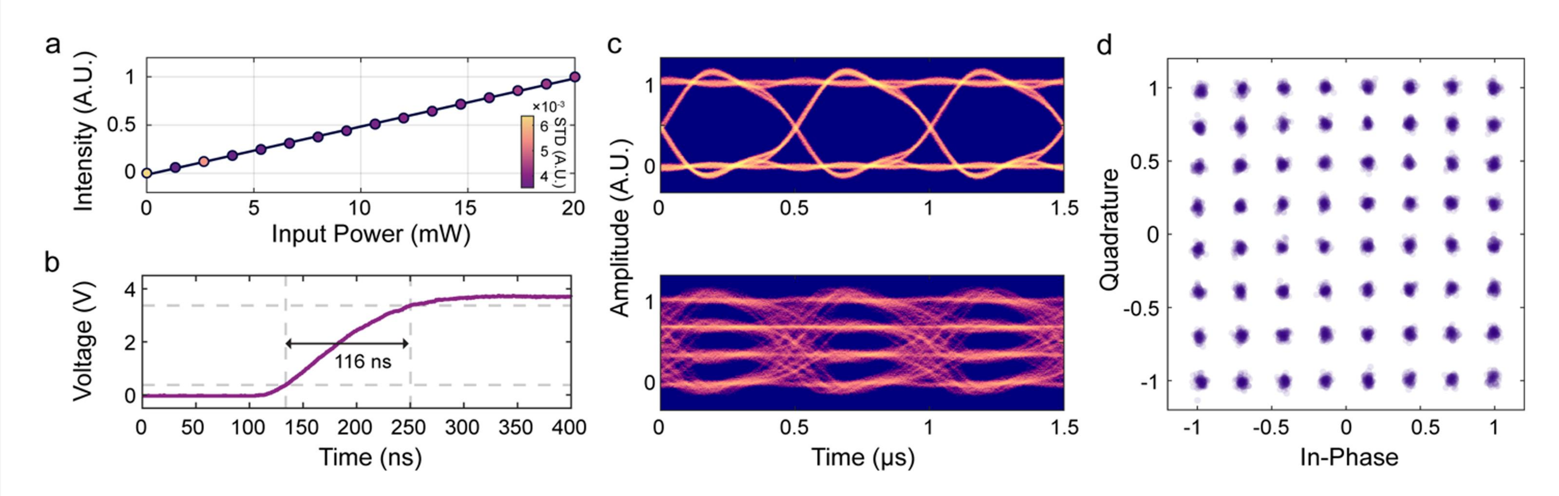


Multi-beam Steering & Communication

- Generates 2D array of beams (4x21).
- Achieved 30 dB on-o contrast with 4 beams generated at the same time.
- Generates 579 spots/mm2.



- Transmits data through free-space optical link using 64-QAM modulation at 6 Mbps.



References

[1] Li, Bingzhao, Qixuan Lin, and Mo Li. "Frequency–angular resolving LiDAR using chip-scale acousto-optic beam steering." Nature 620.7973 (2023): 316-322.

[2] Lin, Qixuan, Shucheng Fang, Yue Yu, Zichen Xi, Linbo Shao, Bingzhao Li, and Mo Li. "Optical multi-beam steering and communication using integrated acousto-optics arrays." arXiv preprint arXiv:2409.16511 (2024).

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