FREQUENCY RESOLVED ANGULAR MODULATION BEAM STEERING

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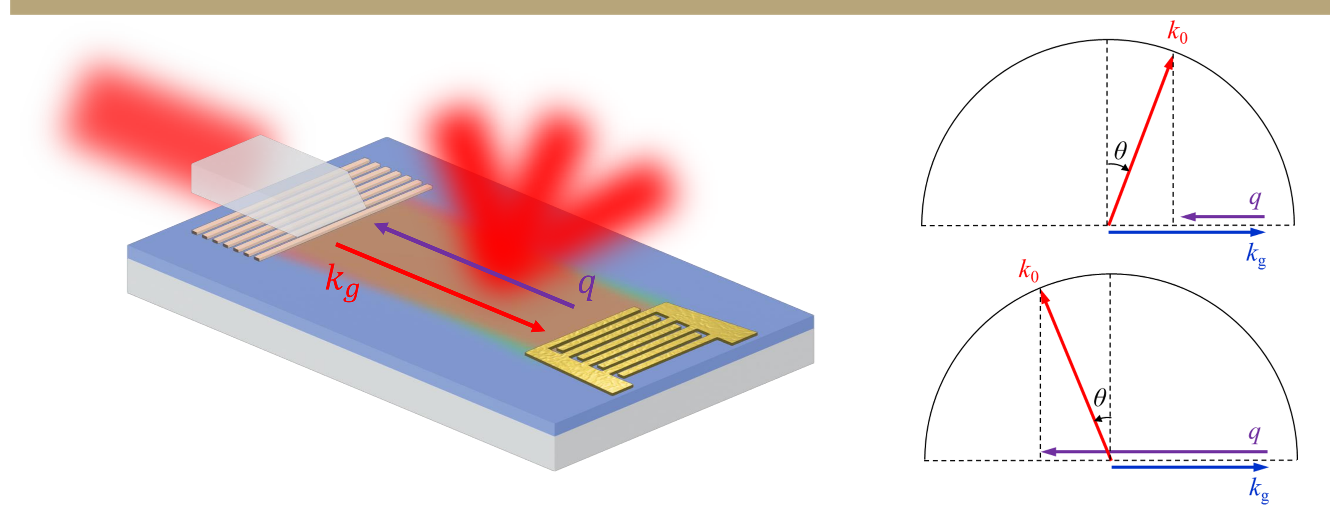
Introduction

- Solid-state beam steering is the key component in various applications such 3D sensing, imaging, and ranging, converging into emerging LiDAR technologies.
- Acousto-optic device based on Brillouin scattering of light by sound wave enables the continuous on-chip beam steering and large emission aperture.
- Acousto-optic beam steering (AOBS) automatically encodes the steering angle in the frequency shift of the steered light beam, achieving the frequency resolved angular modulation.

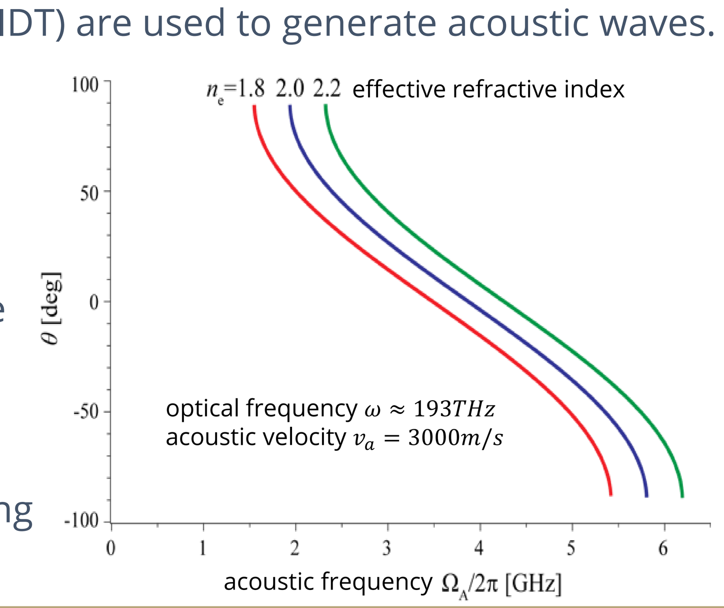
Acousto-optic Beam Steering Operation Principles



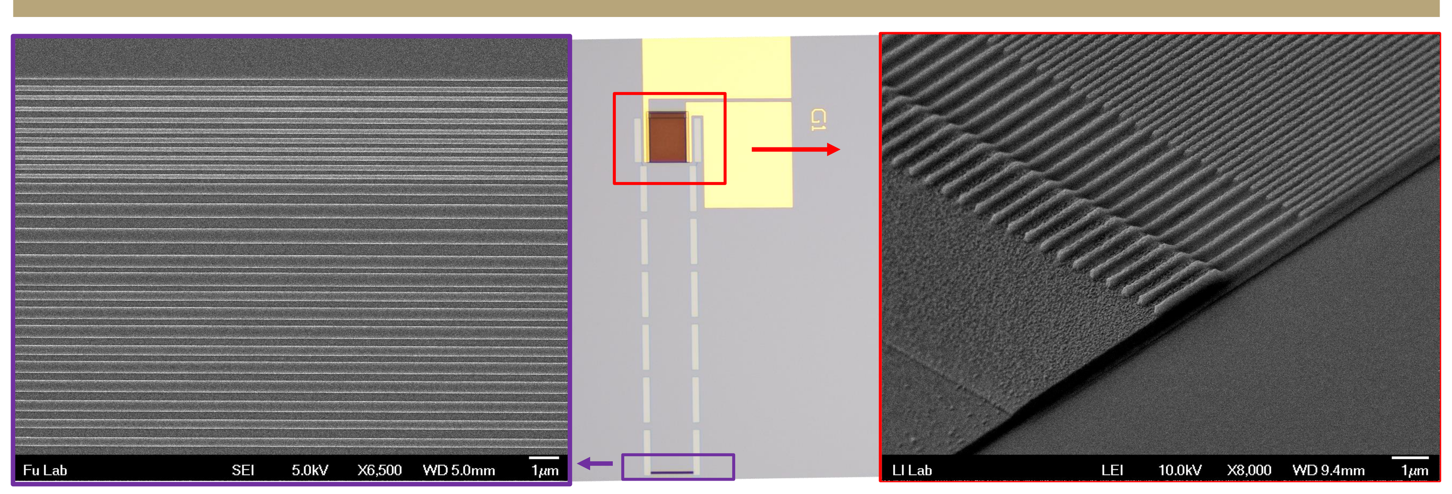
- The basic idea of AOBS is the guided optical wave deflected by a moving refractive index grating generated by the guided acoustic waves, where the phase-matching condition is applied, $k_0 sin\theta = k_g - q$, as shown in the figures above. Grating couplers are used to couple the freespace light into the guided mode and interdigital transducers (IDT) are used to generate acoustic waves.
- As shown in the right figure, out-of-plane steering angle θ can be also described as,

$$sin\theta = n_e - \frac{\Omega_a/v_a}{\omega/c}.$$

- Due to the energy conservation, the steered beam has an anti-Stoke frequency shift by the acoustic frequency Ω_a, which relates its frequency $\omega' = \omega + \Omega_a$ to the steering angle θ.



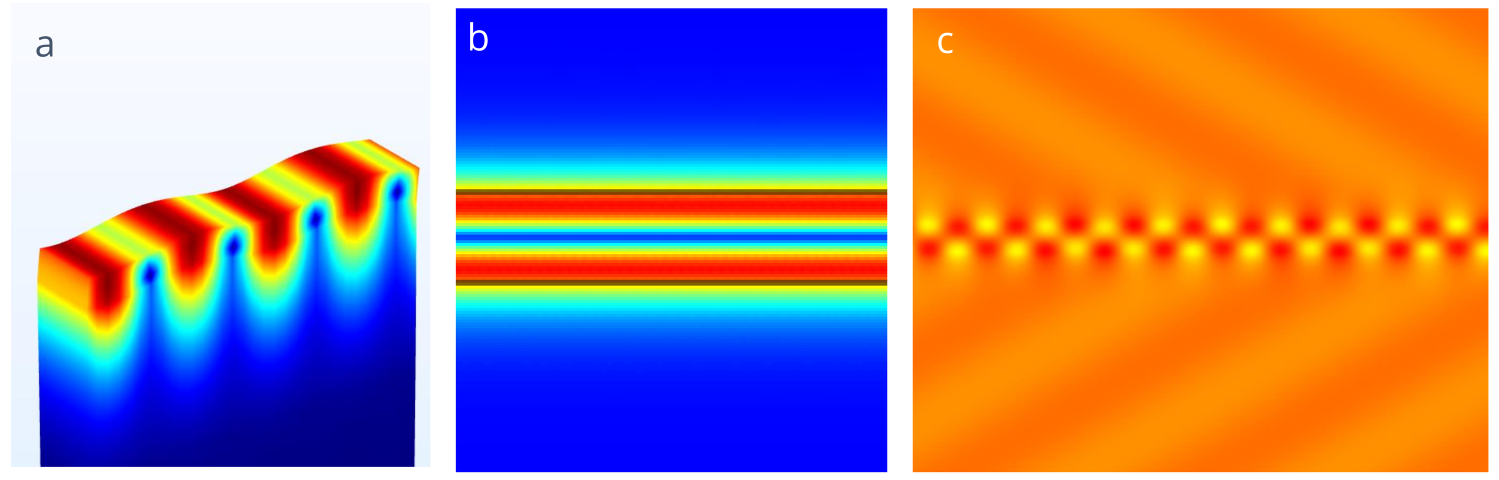
Device Structure



Images of the fabricated device, fabricated with lithium niobate on insulator wafer

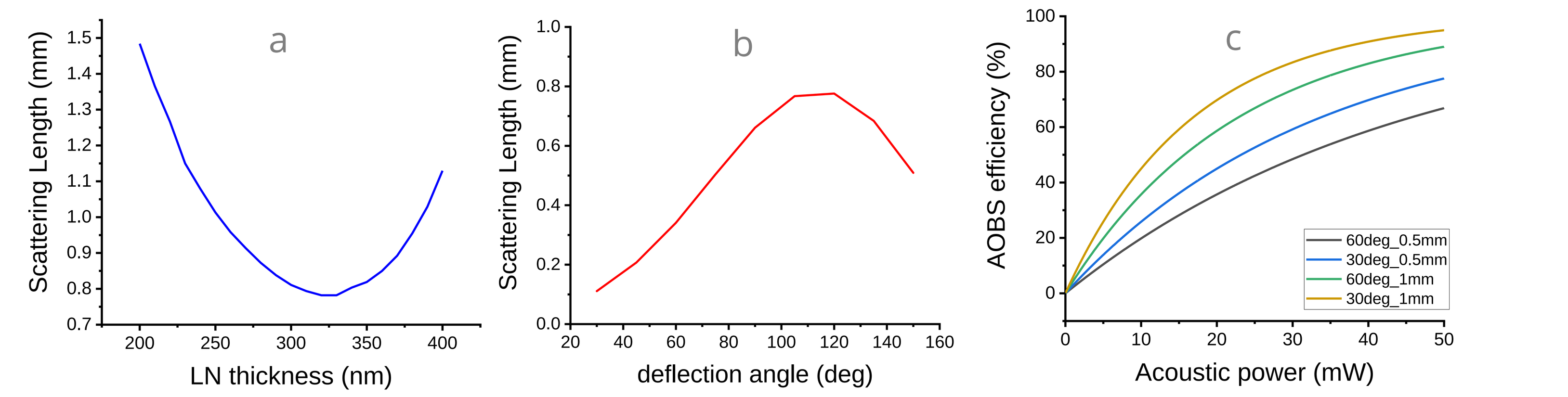
Simulation and Optimization

- COMSOL Multiphysics is used for the simulation and optimization of the guided optical mode, acoustic mode and AOBS efficiency.
- As shown below, the fundamental Rayleigh mode (R0) and high order transverse electric mode (TE1) are applied to maximize the AO scattering efficiency.



a. Guided acoustic wave mode R0. b. Guided slab TE1 mode. c. Optical wave steered by the acoustic wave induced index grating

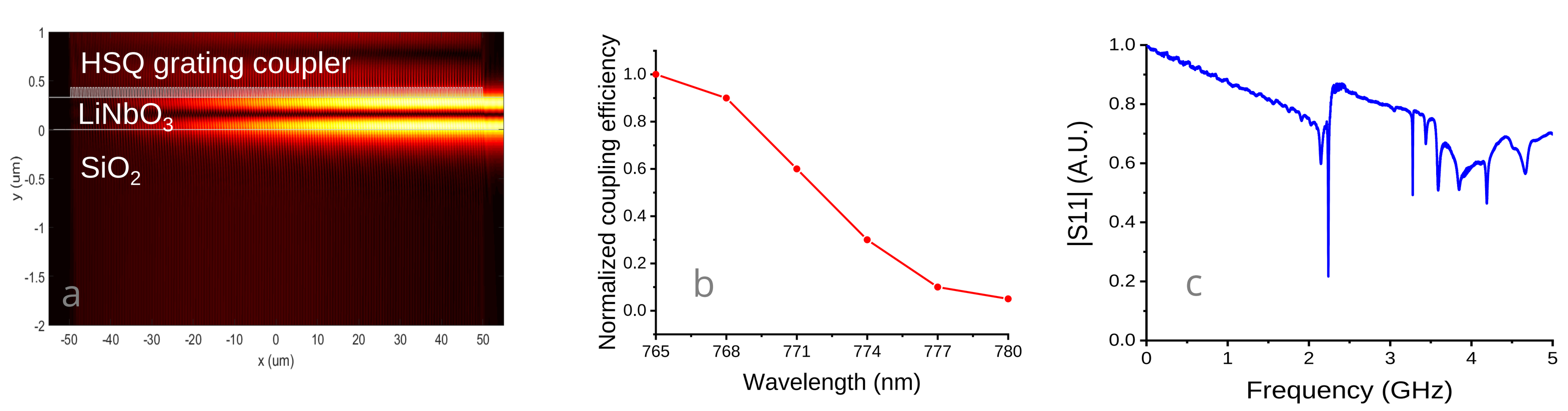
- AOBS efficiency can be described as, $\eta = 1 - \exp(-\alpha z) = 1 - \exp(-z/L)$, where α is the unit scattering efficiency, L is the effective scattering length and z is the AOBS aperture size. Therefore, larger aperture with shorter effective scattering length has better performance.



a & b. Optimization of the scattering length with respect to the lithium niobate thickness and the steered angle. c. AOBS efficiency with respect to different aperture size, steered angle and input acoustic power

Device Characterization

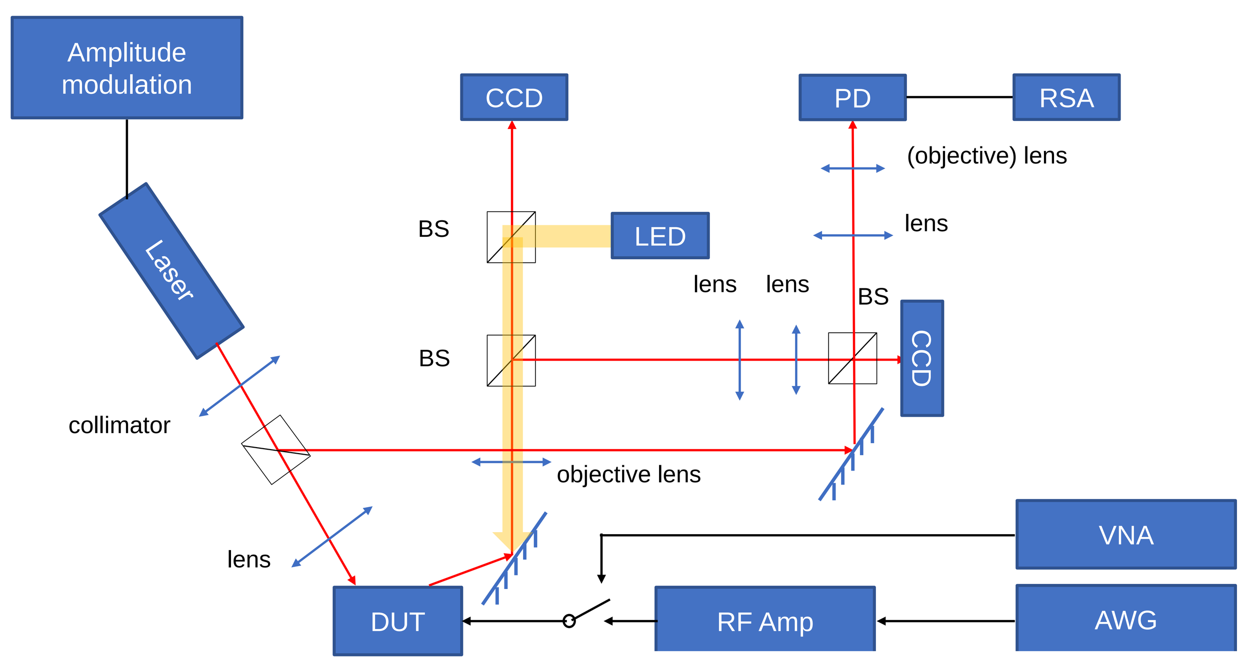
- Coupling efficiency of the input grating coupler is characterized by the transmission of a pair of opposite grating couplers.
- Transduction efficiency of the IDT from electromagnetic wave to acoustic wave, is characterized by the reflectance S11.

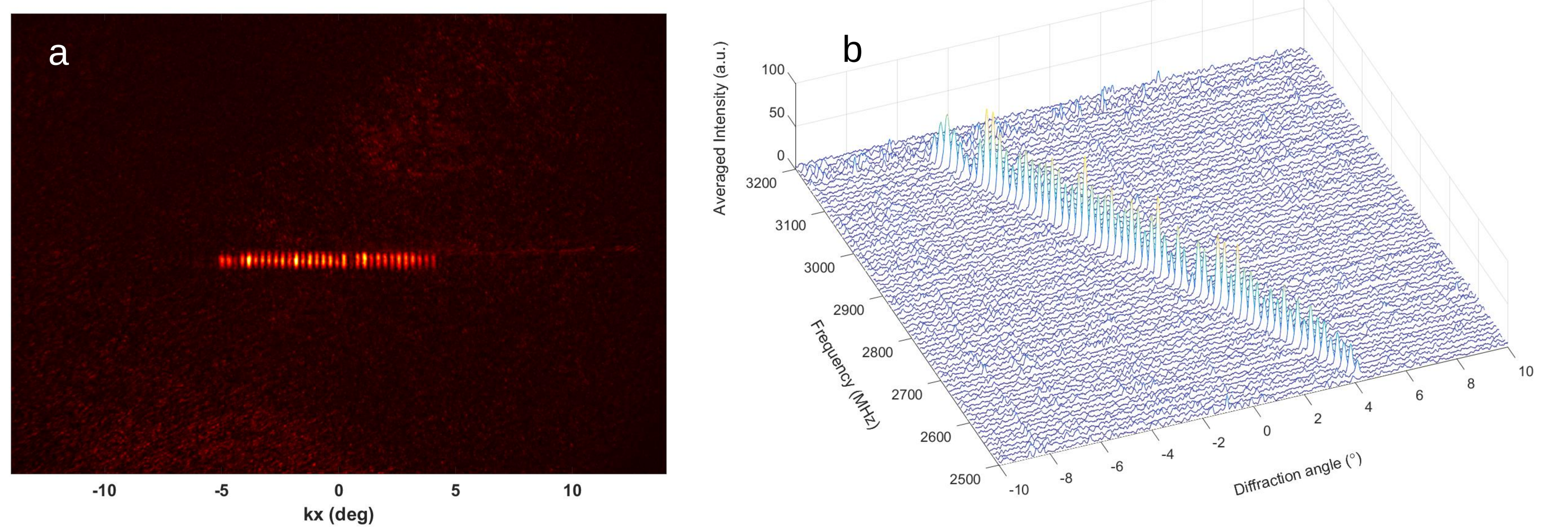


a. Simulated mode profile of the input HSQ grating coupler. b. Normalized coupling efficiency of the input grating coupler. c. Reflectance (S11) of the IDT.

Measurement Result

- Measurement setup is shown in the following figure.





a. Steered beam captured by the right CCD camera, which located at the k-space plane.
b. Steered beam angle with respect to the acoustic wave frequency.

- We demonstrated an integrated frequency resolved angular modulation AOBS device fabricated on LN-on-insulator substrate.
- We achieved an AOBS efficiency as high as 0.1%, resulting in a $2\mu W$ output beam power. The steering angle range from -5 deg to 5 deg, with an angular resolution as small as 0.1 deg, resulting in 100 distinguished spots.

Future Work and References

- Improving efficiency to 10% by changing the AO material from LN to gallium phosphide, improving the optical grating coupler coupling efficiency and optimizing the IDT design.
- Finishing the LiDAR demonstration.

[1] Huan Li, Qiyu Liu, Mo Li, "Electromechanical Brillouin scattering in integrated plannar Photonics", APL Photonics 4, 080802 (2019)
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[3] Han Zhao, Bingzhao Li, Mo Li, "Scaling optical computing in synthetic frequency dimension using integrated cavity acousto-optics", arXiv:2106.08494 (2021)

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