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Visible light multichannel on-chip acousto-optic beam steering

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Abstract: We demonstrate a chip-scale multichannel acousto-optic beam steering (AOBS) technique on the lithium niobate on insulator (LNOI) platform, realizing compact visible-light continuous beam steering.

1. Introduction

Quantum computing offers a promising solution to tackling complex problems that are intractable by classical computers. Cold atoms and trapped ions, owing to their intrinsic properties as naturally identical qubits, are ideal for quantum computing and metrology. However, bulky optical control systems used for qubit manipulations pose a substantial challenge to scaling up such systems. Although programmable optical tweezers with spatial light modulators (SLM) and bulk acousto-optic deflectors (AOD) have shown successful trapping and deterministic assembly atoms [1, 2], achieving scalable independent coherent optical manipulation of a qubit's internal states for local gate operations remains difficult. To overcome this challenge, there is a need for miniaturized multichannel solid-state beam steering technologies that operate in the visible light range, replacing the current bulk-optics instrumentation for large-scale atomic quantum computing. Integrated photonic light emission based on static grating structures has been demonstrated [3, 4]. Here, we report on a dynamically tunable chip-scale multichannel beam steering technique employing acousto-optic beam steering. By confining both acoustic waves and light in a waveguide, the integrated acousto-optics enhance the density of the acoustic waves, resulting in high scattering efficiency within a small footprint and a lower RF power consumption compared to the conventional bulk acousto-optic components[5,6]. We fabricate 4-channel AOBS devices on an LNOI chip, each operating at visible range with dynamic amplitude/phase control and multi-beam generation capability. This multichannel AOBS technology offers a promising compact beam steering platform for potential applications in quantum computing and metrology.

2. Principle of integrated AOBS

As shown in Fig.1a, prototype AOBS devices are fabricated on an x-cut LNOI (300 nm thick LN) chip, each device consists of two components. On one end, a linear-chirped interdigital transducer (IDT) made of 180 nm aluminum film electromechanically excites acoustic waves utilizing LN's strong piezoelectricity. On the other end, an optical grating coupler is patterned in hydrogen silsesquioxane (HSQ) electron beam resist, which couples light from the laser to the high-order transverse electric mode (TE1 mode) of the LN planer waveguide. The TE1 mode is then scattered by the counterpropagating acoustic wave through the Brillouin scattering process. The design of the AOBS device is based on the phase-matching condition and the dispersion relation of the acoustic and optical mode, shown in Fig.1b. The acoustic wave with gigahertz frequency has large enough wavenumber K, which scatters the light from the guided TE1 mode directly into the free space. According to the phase-matching condition: $k0 \cos(\theta) = kg - K = kg - \Omega/v$, where kg is the guided optical mode wavenumber, $k0=\omega 0/c$ is free space optical wavenumber, θ is the scattering angle measured from the surface of the waveguide, and Ω and v are the acoustic frequency and phase velocity, respectively. Therefore, the scattered light can be continuously steered by changing the frequency of a single RF drive. Fig.1c shows an optical image of a 10-channel device array fabricated on one chip. With the well-developed LN fabrication technologies, we can confine the light and acoustic waves in etched waveguides, which allows us to use fiber coupling and potentially integrate with on-chip lasers and modulators to further reduce the form factor of the optical control.

3. Characteristics of AOBS and multi-beam generation

We experimentally demonstrated the AOBS and characterized the steered beam by its momentum space (*k*-space) profile. We first drive the IDT at a single RF frequency. The steered light was then captured by a CCD camera and the angular information can be calculated from the k-space image. Fig.1e shows the dependence of the steering angle when sweeping the RF frequency across the IDT bandwidth from 2.7 GHz to 3.15GHz. A typical divergence angle of the steered beam is 0.11º with a 10º field of view. In addition, the coherence of the AOBS process also allows multiple tones of acoustic waves to co-propagate in the aperture. Each tone scatters the light into a different angle and thus together they generate multiple beams simultaneously. Fig.1f shows 15 beams generated by a single AOBS channel. Beam generation in the other direction is accomplished with multiple AOBS channels by adding a cylindrical lens.

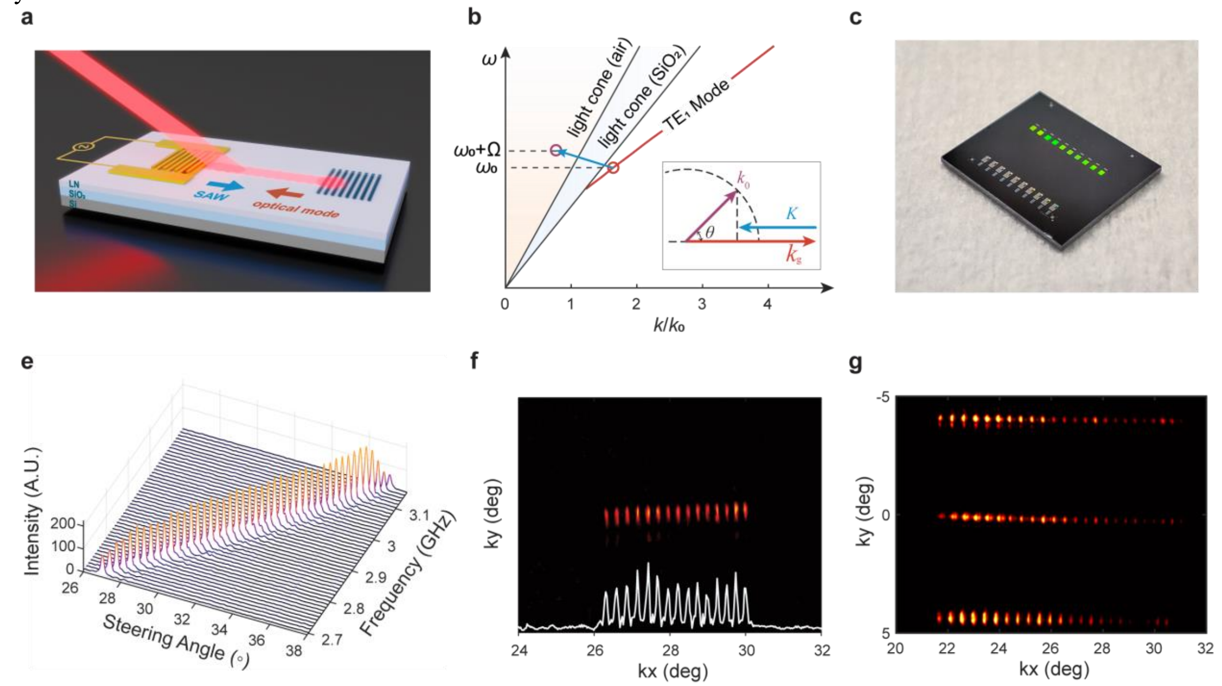

Fig. 1. Principle and characteristics of integrated acousto-optics beam steering. (a) Schematic illustration of the AOBS device. (b) Dispersion diagram of the acousto-optic Brillouin scattering process. The dispersion curve of the TE1 mode of the LN planar waveguide is simulated and plotted as the red curve. The counter-propagating acoustic wave (blue arrow) scatters the light into the light cone of air (purple circle in the yellow-shaded area)—inset: momentum vector relation of the Brillion scattering. The light is scattered into space at an angle θ from the surface. (c) An optical image of the 10-channel AOBS device array. (e) Frequency-angle (Ω-θ) relation of the steered beam with the inset shows the k-space image of the steered light with a single-frequency RF drive. (f) multi-beam generation simultaneously by one channel and the cross-section intensity profile (white curve). (g) Lens-assisted 3-channel 2D beam steering. One spot is turned on at a time.

4. Conclusion

We demonstrated a prototype integrated multichannel acousto-optic beam steering technology on the LNOI platform at the visible light range, realizing on-chip dynamic beam steering and multiple-beam generation, paving the way to large-scale optical control for an array of individual atoms or ions.

5. References

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