High-intensity spatial-mode steerable frequency up-converter toward on-chip integration

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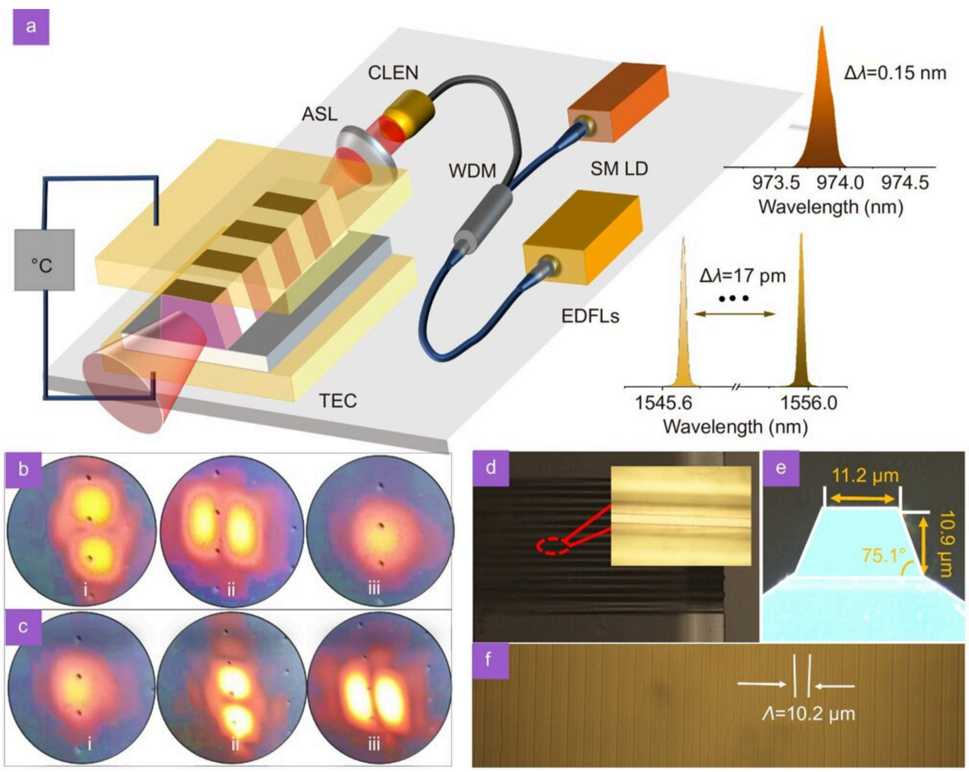

a) Schematic of the temperature/wavelength-dependent spatial mode steerable SFG device; (b) in the temperature steering scheme, the detected up-conversion lights with (i) TM01, (ii) TM10, and (iii) TM00 modes at 30°C, 40°C, and 60°C, respectively, on a white broad; (c) in the wavelength steering scheme, the detected SFG lights with (i) TM00, (ii) TM01, and (iii) TM10 modes at 597.46, 597.99, and 598.41 nm, respectively, on a white broad; (d) microscope image of the fabricated PPMgLN waveguide array on an LT wafer (Inset: detail profile of the third waveguide); (e) cross-section view of the fifth waveguide selected in the experiments; (f) the fabricated polling structure with a period of 10.2 μm. EDFLs, Erbium-ion doped fiber laser system; SM LD, single-mode fiber-coupled diode laser; WDM, wavelength division multiplexer; CLEN, collimating lens; ASL, aspherical lens; TEC, thermoelectric cooler. Credit: *Opto-Electronic Science* (2024). DOI: 10.29026/oes.2024.230036

A study published in *Opto-Electronic Science* discusses high-intensity spatial-mode steerable frequency up-converter toward on-chip integration.

Integrated photonic devices consisting of micro-lasers, amplifiers, optical waveguides, frequency converters, and modulators on a single chip, enabling control over photon's spatial modes, frequencies, angular momenta, and phases, are essential for preparing high-dimensional quantum entangled states, high-capacity photon information processing, all-optical communication, and miniaturization of photonic computing.

However, current nonlinear waveguide devices, integrating spatial modes and photon frequency conversions, heavily rely on external optical path control and spatial light modulators, failing to meet the crucial requirement of on-chip integration for photonic devices.

To address this, the authors of this article propose the on-chip integration of a spatial mode steerable nonlinear frequency up-conversion device based on spatial mode competition under high mixing light intensity. This approach achieves high-intensity spatial modes during nonlinear frequency conversion of an LN waveguide and can be controlled by tuning both temperature and fundamental wavelengths.

Based on the inter-mode phase matching principle of optical waveguide, the temperature, fundamental signal frequency, and intensity conditions required for the generation of different spatial modes during the nonlinear up-conversion process were deduced, obtaining the structural parameters of the spatial-mode steerable frequency up-conversion waveguide.

Subsequently, utilizing photolithography combined with the process of forming structure inversion and precision cutting techniques with a diamond knife, they fabricated PPLN multi-mode waveguides that meet the conditions for inter-mode phase matching and nonlinear frequency up-conversion.

Using a 976 nm DFB laser as the pump light and a C-band tunable narrow linewidth fiber laser as the signal light, steerable high-intensity outputs between TM01, TM10, and TM00 modes were achieved under variable temperature and signal light wavelengths.

Since this process does not require additional optical path control or using bulky spatial light modulators, it lays an important foundation for further on-chip integration of high-dimensional quantum entanglement devices and large-capacity mode-division multiplexing devices.

More information: Haizhou Huang et al, High-intensity spatial-mode steerable frequency up-converter toward on-chip integration, *Opto-Electronic Science* (2024). DOI: 10.29026/oes.2024.230036

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