Mid-Infrared 2-D Beam Steering

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Abstract: We will experimentally demonstrate optical beam steering in the mid-IR spectral region (around λ=4.6μm) in the InP/InGaAs platform. Both wavelength and phase tuning are utilized for two-dimensional (2D) steering in elevation and azimuthal directions respectively.

The development of a robust component technology base in the mid-IR spectral region is a continuous scientific endeavor. While spectroscopic applications continue to make the most use of this region, other applications become possible with the development and integration of new devices. Our current work contributes to this advancement. The optical beam steering device developed here has a proposed application for countermeasures, but other applications involving, for instance, spatial mapping or directed energy transfer can be envisioned.

In the near-IR spectral region notable progress in beam steering has been made by the Bowers and Chen groups [1, 2]. Both groups used a combination of wavelength and thermo-optic phase tuning to demonstrate 2-D steering with fields-of-view (FOV) around 15°×20° and beam widths around 0.5°×1.2°. Additionally, the Chen group has shown that an unequal spacing of array elements results in a net far field profile with a single main lobe and minimal side lobes due to destructive interference on non-overlapping side lobes [3]. In the mid-IR the Razeghi group has demonstrated 1-D steering by wavelength tuning in the InP/InGaAs platform, monolithically integrated with a quantum cascade laser (QCL) source [4].

In the current work we are combining the knowledge gained from the previous works in both the near-IR and mid-IR to produce 2-D beam steering in the mid-IR, in the InP/InGaAs platform. Initial work is focused on demonstrating both wavelength tuning for elevation (θ) steering and thermo-optic phase tuning for azimuthal (ψ) steering (see directions in Fig. 1). Key elements of this demonstration are heaters for thermo-optic adjustment and output gratings for wavelength-dependent deflection. By thermo-optic adjustment we mean that heating modifies the index of the waveguide which in turn modulates the phase.

Fig. 1(a) shows a schematic of the proposed device structure. Light from a monolithically integrated quantum cascade laser is coupled into a waveguide splitter that splits the light into several equal optical paths. In each path, electrodes are integrated on top of waveguides to enable phase shifting by thermally induced changes in the refractive index. In this work, we investigate the passive waveguide section only wherein light will be end-fire coupled into the waveguide splitters from an external QCL emitting at λ~4.6μm. The passive waveguide cross-section is shown in Fig. 1(b). The optical mode is confined to the InGaAs layer. The metal heater sits atop the epitaxial stack, separated from the InGaAs waveguide by the InP upper cladding. The InGaAs core is heated by current flow across the stack. At the emission region the InGaAs layer with grating is shallow etched, deflecting the beam to free space. The emitter gratings are 500 nm deep and grating periods range from 1.20 to 1.75 μm.

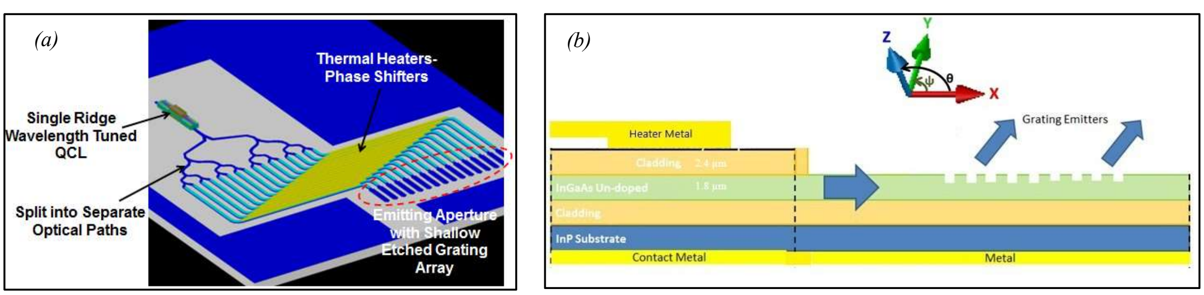

Fig. 1: (a) Device Schematic of monolithically integrated mid-infrared 2D optical beam steering device. (b) Schematic side-view of the device structure in the heating and grating regions (not to scale). Also shown is the orientation of the elevation (θ) and azimuthal (ψ) angles.

Fig. 2(a) shows array factor calculations for an equally spaced array of 32 output emitting grating elements, with a center to center spacing 2.5λ. Fig. 2(b) shows the directivity of an antenna formed from an unequally spaced array of emitters, comprising 4 sub-arrays with different spacing, with each sub-array comprising 10 equally spaced elements. Fig. 2(c) and (d) show the simulated optical mode and device index cross-sections. An oxide passivation is considered for electrode isolation. Mode overlap calculations of the fundamental TM_{00} mode, using Lumerical Mode indicate a 2.5×10^{-5}% overlap with the top metal heating contact and a 3.3×10^{-6}% overlap with metal extending down the side of each waveguide to bond pads. Considering that gold absorbance is $8.6\times10^5 cm^{-1}$ (3.7×10^6 dB/cm)at λ=4.6μm, the negligible mode overlap results in a mode propagation loss <0.2dB along the length of the 2mm long metal pad. For a L=2mm long metal heater, phase shift $\Delta\phi= (2\pi/\lambda).(dn_{eff}/dT).\Delta T.L$ calculations from Mach-Zehnder interferometers, indicate that a π phase shift requires a ΔT=5.75K temperature rise in the component waveguide for ~10mW heating power, which can be achieved by passing ~100mA current through the undoped InGaAs/InP waveguides. In order to achieve φ=15-degree azimuthal steering, by applying the equation $\sin\varphi=\lambda\phi/2\pi d$, where d is the emitter spacing, λ is the operating wavelength and π is the uniform phase difference between array elements, we estimate that required phase shift $\phi=1.29\pi$ ϕ for a uniformly spaced array. As noted in [2], the analytical calculations provide a starting point, and exact values are to be determined from fabricated devices. The analytical calculations can be utilized to calculate heat sinking attributes.

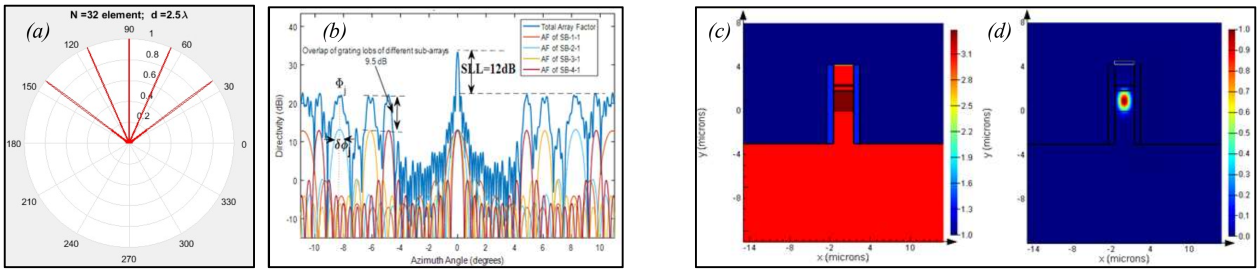

Fig. 2: (a) Array factor of an equally spaced array of 32 emitters spaced by 2.5λ. At λ=4.6μm, the center-to-center emitter separation is thus 11.5μm. (b) Directivity simulation of an unequally spaced array of emitter elements with 4 subarrays, and 10 equally spaced elements in each sub-array. (c) Refractive index profile and (d) TM_{00} mode profile of the propagating mode.

Fig. 3 shows the first generation layout. The input waveguide is split-cascaded down to 32 separate waveguides. The heating strips run 2 mm long across each waveguide and are connected separately to independent wire bond pads for independent current control. Fig. 4 shows scanning electron micrographs (SEMs) and microscope images of fabricated devices. Measurements are in progress. Waveguide propagation loss 4dB/cm were measured in preliminary devices for the TM_{00} mode.

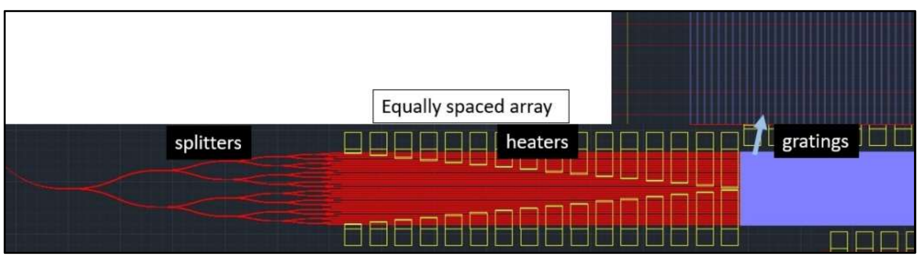

Fig. 3: CAD layout showing the three main sections.

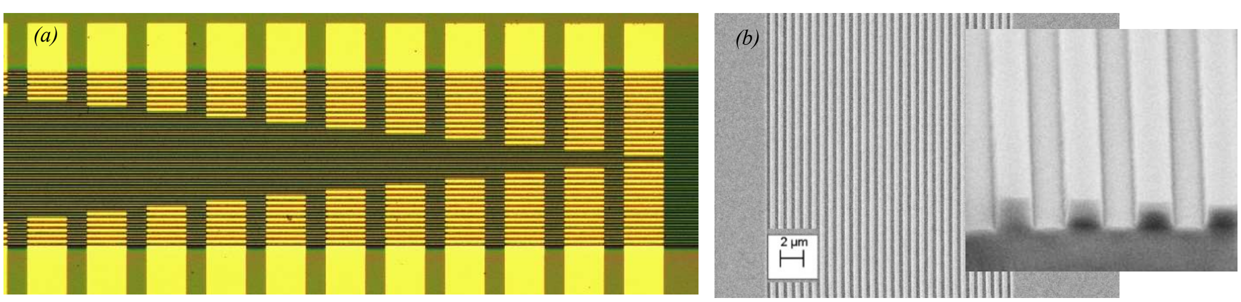

Fig. 4: (a) Microscope image of the heater region. (b) SEM image of grating with zoom-in.

In combination with other demonstrations our group has carried out for integration of active and passive components in the mid-IR InP/InGaAs platform [5, 6], the work presented here will lead to the realization of the monolithic beam steering architecture in Fig. 1(a). This research is supported by the U.S. Navy SBIR Contract #N68936-19-C-0011. The content of the information does not necessarily reflect the position or the policy of the Government, and no official endorsement should be inferred.

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