# Electro-Optic Beam Steering Enhancement by Etching a Cylindrical Facet within an InP Photonic Integrated Circuit

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*Electro-optical steering devices based on a single aperture allow an optical beam to be steered in the near field of the device by means of multimode interference mechanisms [1]. We show that a translation of the near field beam steering into far field beam steering can be achieved by applying a curved facet at the output of the steering device. A cylindrical facet of 20 μm radius is etched within an InP electro-optical steering device to enable a far field steering of 5° with a maximum applied voltage of 6 V.*

## Introduction

Integrated optical components capable of steering an optical beam may play an important role in LIDAR [2], printing [3], holographic memories [4] and communication [5].

Several integrated optical beam steering techniques have been proposed in the literature including twin striped lasers, Optical Phased Arrays (OPAs) and slab waveguide based techniques. Twin striped lasers [6] can steer an optical beam in the near and far field demonstrating a far field tuning range of 10° with currents of the order of 100mA. OPAs [2,7] can achieve a beam steering range of 51° with individual phase control on each emitter, but high numbers of densely integrated emitters are required for the best beam quality. Solutions based on wide waveguides [1] allow a flat-phase-front, single-lobe beam to be steered across the chip facet. Studies into beam steering from single emitters have mainly considered steering in the near field, but the opportunity to steer light in the far-field also has important application [2]. Researchers have explored the possibility for on chip lensing using curved facets [8,9] but to the best of our knowledge, this concept has not been exploited to improve the steering performance in the far field of an integrated beam steering device with single aperture.

In this work, we have designed a system exploiting our recently proposed concept for voltage actuated beam steering in a single aperture [10] and on-chip lensing to enable steering in the far field of a single lobe field by controlling only two electrodes. This approach converts the near field shift of a single lobe beam into a far field steering by monolithically integrating a lens at the output facet of the optical chip. We present the concept, the experimental realization and characterization. A comparison is made for two different devices: one with an as-cleaved output and a second with a focused ion beam etched curved facet to show the role of the curved facet in beam steering.

## Device and principle of operation

The schematic 3D view of the as-cleaved device (Fig. 1a) as used for the comparison and the curve-etched facet are shown in Fig. 1. The flat facet circuits are produced by Smart Photonics using JePPIX.eu [11].

The steering section consists of a 14.5 μm wide ridge multimode waveguide with two twin parallel electrodes placed on top of it. The steering section is as long as the electrodes.

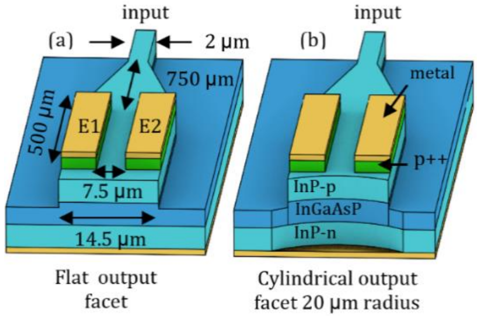


**Fig. 1:** a) Beam steering device with flat output facet and b) with curved output facet.

A length of 500 µm is designed for the electrodes in order to maximize the steering effect. The taper section is a 750 µm long linear adiabatic taper. The gap width between the p-electrodes E1 and E2 is 7.5 µm to ensure electrical isolation between the two p electrodes. The p++ contact width is designed to be 3.5 µm to ensure adequate electrical contacting.

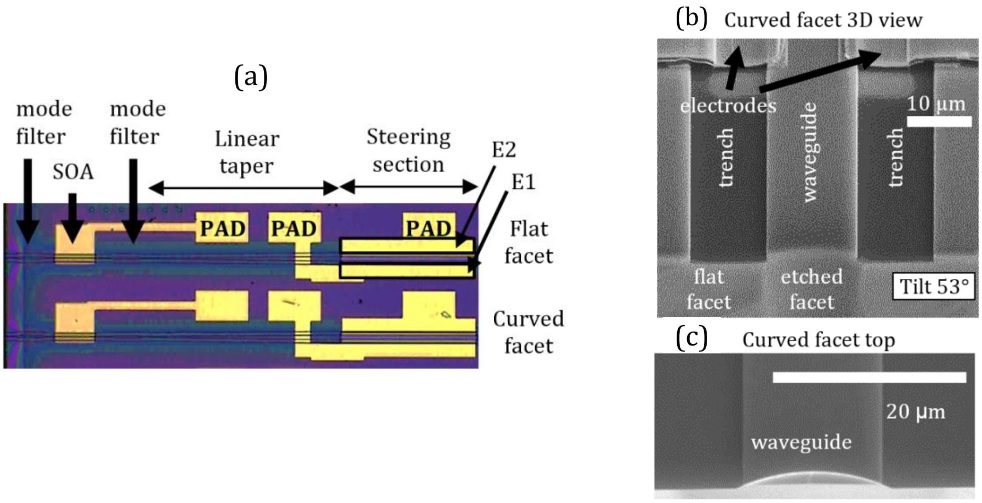


**Fig. 2:** a) Annotated microscope photograph of the tested PICs. Scanning electron microscope image for b) 3D view and c) topview of the curved facet.

The beam can be steered either to the left or to the right side of the output facet depending on the biasing voltage applied to the p-type electrodes.

The curved facet allows the lateral beam movement to be converted into a phase front reconfiguration since a different change in phase front will be added from the cylindrical lens according to the beam position. The curved facet has been etched by post processing by means of focused single pass ion beam etching with an acceleration voltage of 30 kV, beam current of 2.7 nA and dwell time of 2 ms with 32.4 nm pitch. The etching path is an inside-out circular spiral with outer radius of 20 µm, overlapping the optical chip for an effective etched area of 16.8 µm$^2$. An optical microscope image of the two test PICs containing the steering devices is shown in Fig. 2a. With the exception of the facets, the two devices are identical. The inputs are on the left side of the chip. A semiconductor optical amplifier (SOA) is placed after the input for alignment purposes with external optical sources. A 3D view and a top view of the curved facet are shown respectively in Fig. 2b and Fig. 2c.

## Experimental setup

The effect of the on-chip cylindrical facet has been studied by the experimental setup shown in Fig. 3. First, we compare the two steering devices by near field characterization to show that the beam at the chip facet has comparable movement for both the flat and cylindrical facet devices. The near field measurement setup is shown in Fig. 3a. An external laser at 1465 nm and output power of -6dBm is fed through a polarization controller (to set the TE polarization) into the chip by exploiting a lensed single mode fiber. The SOA is operated near transparency. The optical field at the facet of the chip is collimated by an infrared aspherical lens with focal length of 2 mm and focused by the lens f1 with focal length 750 mm. A magnification of 375 is achieved for the imaged beam. The image is acquired by a 320 x 256 pixels XENICS IR camera. The scheme of the far field experimental setup is shown in Fig. 3b. The lens f1 is replaced with the lenses f2 and f3 of focal length 150 mm and 250 mm respectively. The lens f2 makes a magnified image of the near field which is collimated by f3. The Fourier plane is created at 250 mm from f3 and acquired from the camera. The imaged far field window represents a 162° x 130° wide window. The voltage applied to the electrode E1 (Fig. 1) is swept from 0 V to -6 V and back to 0 V with a step of 0.2 V, while the voltage applied to the electrode E2 is initially fixed at 0 V.

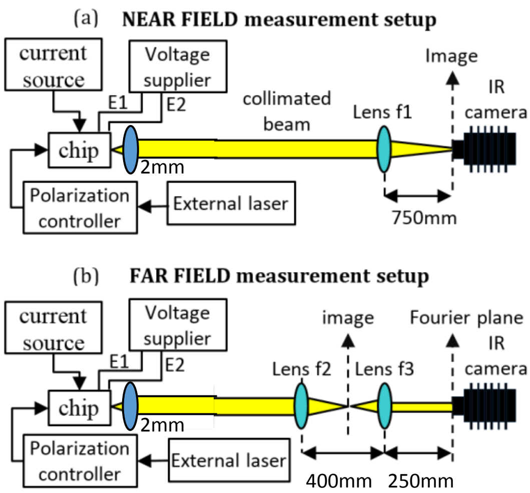


**Fig. 3:** a) near field measurement setup; b) far field measurement setup.

Afterwards, the complementary electrical configuration is applied to E1 and E2 and the voltage sweep is repeated for electrode E2. The electrical current drawn by the device is monitored during the beam steering measurement, a maximum leakage current of 40 mA is recorded and attributed to the low resistance top cladding path present in between the p-electrodes. For every voltage step the beam profile is recorded by the camera. For both the near field and the far field a vertical integration of the recorder beam is applied to reduce a low level (2.7%) interference pattern which may be attributed to substrate optical leakage.

## Beam steering results

The beam steering in the near and far field is quantified in terms of mean displacement of the recorded intensity field profiles. Fig. 4 shows for both the flat and curved facet devices the beam steering in the near and far field. Fig. 4a shows a total beam steering displacement of 0.8 µm and 1.2 µm for the flat and the 20 µm radius facet device respectively. The far field steering in Fig. 4b is not significant for the flat facet device whereas it reaches a total tuning range of 5° in the curved facet case. The far field magnification effect of the lens is accompanied by a full with half maximum (FWHM) increase, from 13° to 33°.

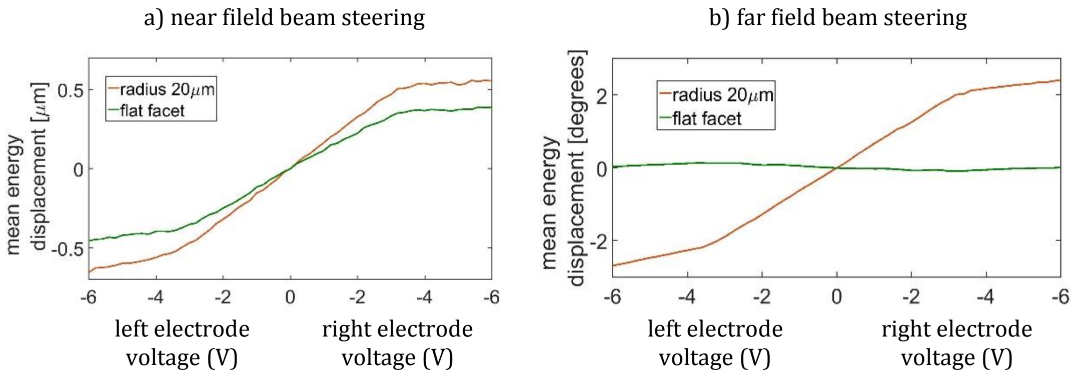


**Fig. 4:** a) mean energy displacement in the near field; b) mean energy displacement in the far field.

## Conclusions

We have etched a cylindrical shape facet at the output of a beam steering device based on InP technology in order to enhance the far field steering. A control experiment has been performed in order to validate the concept. The integration of the curved facet has resulted in an improvement of the full steering angle up to 5° although at the expense of a higher divergence beam.

## References

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