Half-Horn and Parabola Shaped Electro-Optic Beam Deflectors

Y. Zuo, B. Bahamin, P. Langlois*, V. Aimez* and D.V. Plant
Department of Electrical &Computer Engineering, McGill University, Montréal, Québec, Canada H3A-2A7
**Department of Electrical & Information Engineering, Université de Sherbrooke, Sherbrooke, Québec, Canada J1K 2R1*
Contact:Yiying Zuo tel: 514.398.8053 fax: 514.398.5208 email: yiying@photonics.ece.mcgill.ca

Abstract: We report the design of two electro-optic deflectors. The half-horn and parabola shaped EO scanners provide deflection angles of 2.5°and 3.22° degrees. These are the largest angles reported to date for bulk effect EO scanners.

OSICS codes: (230.2090) Electro-optical devices; (120.5800) Scanners; (060.1810) Couplers, switches and multiplexers.

1. Introduction

Electro-optic (EO) beam deflectors are voltage-controlled beam scanner widely used for applications in scanning and switching. For example, high-speed, low-loss optical switches aimed for future optical networks can be built on EO deflectors [1]. These novel EO deflectors distinguish themselves with a much-improved steering performance, high-speed response and simple fabrication requirements. Patterned ferroelectric crystals such as LiTaO3 or LiNbO3 are first poled to provide the required prism shaped domain structures [2,3]. The application of an electrical field across the crystal can then be used to drive the trajectory of the beam as it travels through the poled wafer. The electric field induces an index change of opposite magnitude on the adjacent domain regions in the EO device, causing the optical beam to refract at the interfaces. Although previous EO deflectors rely on a rectangular geometry, nonrectangular scanners such as horn shaped EO device [4,5] have demonstrated higher deflection sensitivity. In this paper, we will propose two new nonrectangular geometry designs capable of further enhancing the deflection performance of EO beam scanners.

2. Theory and two new designs

The relationship between the refraction index change at the interfaces and the applied electric field is given by (1); where n_0 is the original index, r_{33} is the corresponding electro-optic coefficient of the substrate and V is the applied electric filed along the direction of the dielectric polarization. In rectangular shaped scanner, the maximum deflection angle inside the crystal is given by (2); where L and W are the length and width of the device, respectively. Equation (2) shows that a smaller width W can ensure higher deflection sensitivity. Using this relationship, Ref. [4] describes a horn shaped scanner boasting a width which is flared across the length of the device. The reported scanning sensitivity is twice that of traditional rectangular deflectors.

$$\Delta n = \frac{n_0^3}{2} r_{33} * \frac{V}{D} \quad (1)$$

$$\theta = \frac{2(W - Waist)}{L} = \frac{\Delta n}{n_0} * \frac{L}{W} \quad (2)$$

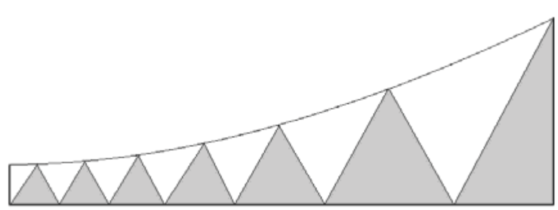

Fig. 1. The half-horn shaped deflectors

In the following, we describe two nonrectangular designs capable of providing a larger scanning angle for a given applied voltage. The first design is designated as the half-horn deflector, where only the upper half of the existing horn-shaped geometry scanner is used. The new shape is depicted in Fig.1. Using ray equations, the lateral position of the beam *X(z)* and the corresponding width *W(z)* are determined by (3) (4) and the angular deflection inside the crystal is (5).

$$\frac{d^2X}{dz^2} = \frac{\nabla n}{n_0} = \frac{\Delta n}{n_0}\frac{1}{W(z)} \quad (3)$$

$$\frac{dW}{dz} = \sqrt{\frac{2\Delta n}{n_0}\ln(\frac{W(z)}{W_0})} \quad (4)$$

$$\theta = \sqrt{\frac{2\Delta n}{n_0}\ln(\frac{W(L)}{W_0})} \quad (5)$$

Due to a further reduced width, the half-horn device will, for a given device size and electric field strength, provide a deflection angle improvement of at least $\sqrt{2}$ times when compared with the original horn shaped device. Since horn-shaped devices have been proven to exhibit better steering performances than rectangular devices [4], our half-horn will therefore boast an even greater deflection angle increase, as shown in Fig. 3.

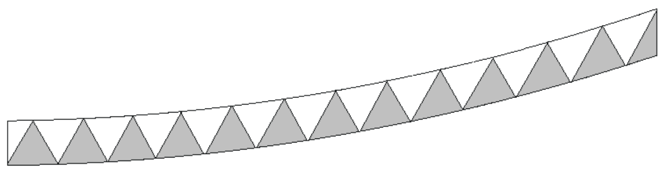

Fig. 2. The parabola shaped deflectors

Further performance improvements can be achieved by strictly following the trajectory of the deflected beam using a parallel geometry. We hence obtain our second nonrectangular geometry design. Depicted in Fig.2, this new geometry is referred to as a parabola shaped EO deflector. Since equation (3) is still valid and *W(z)* is a constant, we can write *X(z)* as (6) and the deflection angle as (7):

$$x = \frac{\Delta n}{2n_0W_0}z^2 + W_0 \quad (6)$$

$$\theta_P = \frac{\Delta nL}{n_0W_0} \quad (7).$$

Although (7) and (2) look similar, the respective widths are different. In rectangular shape, the width has to be much larger than that of the incident beam to accommodate the full bipolar deflection of the beam at the exit. But in the parabola shape, the width only needs to be equal to that of the incident beam.

For a given length and electrical field, a comparison of (2) and (7), clearly demonstrates that the parabola shape will provide a much greater deflection than that obtained using traditional rectangular-shaped devices. Fig.3 is a comparison of the deflection angles of the horn, half-horn and parabola shaped scanner. Here, a device length of 40mm, an entrance width of 450um, and an applied voltage of 1000V on a 500um z-cut LiTaO3 crystal was assumed. The required electric field to obtain a 1° deflection angle is hence 0.62kV/mm, 0.80kV/mm, 1.45kV/mm, 1.69kV/mm for the parabola-shaped, the half-horn shaped, the exiting horn-shaped, and the rectangular-shaped devices, respectively.

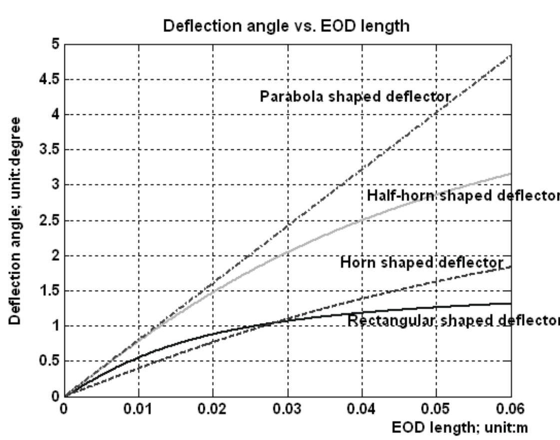

Fig. 3. Comparison of the deflection angles of the three nonrectangular geometry designs

3. Simulation results

The simulations were run using BPM (beam propagation method). We chose a 500μm z-cut LiTaO3 substrate and a device length of 40mm. The entrance width of the parabola shaped deflector is set to 450μm. Similarly, the half horn shaped deflector has an entrance width of 450μm and an exit width of 895μm. The performances of these two new EO switches are shown in Fig4. Since the index of refraction at 1310nm is 2.18 and r_{33} is 30.5pm/V, the change in the refraction index is 6 x10^{-4} for every 1000V applied. The simulated output deflection angle is 3.22° and 2.5° for the parabola and half-horn deflectors, respectively. Table 1 shows the design parameters and BPM results. Compared with the deflection performance of the original horn shaped (1.38°) and rectangular shaped (1.18°) scanners, our two new designs provide a steering improvement factor of approximately 2-3 times.

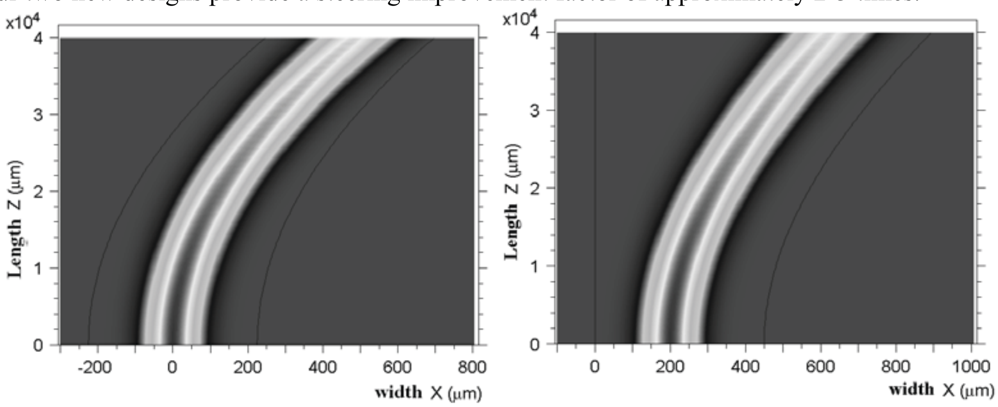

Fig. 4. BPM simulations of the parabola (left) and half-horn (right) shaped deflectors

Table1 simulation compare by BPM

Shape	Length(mm)	Entrance width(μm)	Exit width(μm)	Deflection angle (°)
Parabola	40	450	450	3.22
Half-Horn	40	450	895	2.5
Horn	40	450(for half)	687(for half)	1.38
Rectangular	40	612(for half)	612(for half)	1.18

Experiments on these deflector designs are currently being carried out in our labs. The 500μm z-cut LiTaO3 wafers will first be patterned with the two half-horn and parabola shapes shown before. Domain inversion will be obtained using poling. Following the deposition of a layer of driving electrodes, the substrates will be diced and polished to the design dimensions. Experimental measurements of the deflection performances and sensitivities of these two devices will then be obtained.

4. Conclusion

In conclusion, we demonstrated two new shapes: the half-horn and the parabola shaped electro-optic beam deflectors. These two deflectors will be able to provide 2-3 degrees of steering. The expected angle of deflection of the parabola shaped device is the largest to have been reported to date.

5. Reference

[1]. OSA: E.J. Tremblay, C. Pulikkaseril, E. Shoukry, B. Bahamin, Y. Zuo, M. Mony, P. Langlois, V. Aimez, and D.V. Plant. "A 1x2 fast fiber-optic switch based on electro-optic beam scanning". In Conference on Lasers and Electro Optics (CLEO), CTuFF1 (2004).

[2]. Q. Chen, Y. Chiu, D. N. Lambeth, T.E. Schlesinger and D. D. Stancil, "Guided-Wave Electro-Optic Beam Deflector Using Domain Reversal in LiTaO3", J. L. T **12** 1401-1404 (1994)

[3]. Y. Chiu, R.S.Burton, D.D. Stancil, and I.E.Schlesinger "Design and Simulation of Waveguide Electrooptic Beam Deflectors". J.L.T. **13** 2049-2052 (1995)

[4]. Y. Chiu, J. Zou, D. D. Stancil and T.E. Schlesinger, "Shape-Optimized Electrooptic Beam scanners: Analysis, Design, and Simulation", J. L. T **17** 108-114 (1999)

[5] David A. Scrymgeour, Alok Sharan, Venkatraman Gopalan, Kevin T. Gahagan, Joanna L. Casson, Robert Sander, Jeanne M. Robinson, Fikri Muhammad, Premanand Chandramani, and Fouad Kiamilev, "*Cascaded electro-optic scanning of laser light over large angles using domain microengineered ferroelectrics*", Applied Physics Letters **81** 3140-3142(2002)

Acknowledgements: This work was supported by the Natural Sciences and Engineering Research Council (NSERC) and industrial and government partners, through the Agile All-Photonic Networks (AAPN) Research Network, and NSERC and FCAR scholarships.