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References

1 DIFFIE, W., and HELLMAN, M.E.: 'New directions in cryptograpy', *IEEE Trans.*, 1976, **IT-22**, pp. 644–654
2 HARN, L.: 'Modified key agreement protocol based on the digital signature standard', *Electron. Lett.*, 1995, **31**, (6), pp. 448–449
3 WALDVOGEL, C.P., and MASSEY, J.L.: 'The probability distribution of the Diffie-Hellman key'. Advances in cryptology, AUSCRYPT'92, 1992, Lect. Notes Comput. Sci. (718), (Springer-Verlag), pp. 492–504
4 BLUM, M., and GOLDWASSER, S.: 'An efficient probabilistic public-key encryption scheme which hides all partial information'. Advances in Cryptology: Proc. of Crypto'84, 1985, (Springer-Verlag), pp. 289–299
5 BLUM, L., BLUM, M., and SHUB, M.: 'A simple unpredictable pseudo-random number generator', *SIAM J. Comput.*, 1986, **15**, (2), pp. 364–383
6 VAZIRANI, U.V., and VAZIRANI, V.V.: 'Efficient and secure pseudo-random number generation'. Proc. 25th IEEE Symp. on Foundations of Comput. Sci., 1984, pp. 458–463
7 L'ÉCUYER, P., and PROULX, R.: 'About polynomial-time 'unpredictable' generators'. Proc. 1989 Winter Simulation Conf., 1989, pp. 467–476
8 BRASSARD, G.: 'Modern cryptology, a tutorial', Lect. Notes Comput. Sci. (325), (Springer-Verlag), 1988
9 RABIN, M.O.: 'Probabilistic algorithm for testing primality', *J. Number Theory*, 1980, **12**, pp. 128–138
10 SLOANE, N.J.A., and PLOUFFE, S.: 'The encyclopedia of integer sequences' (Academic Press, San Diego, CA, 1995)

Elliptic waveguide beam focusing and collimating elements in InP: analysis and experiment

C. Wei, J. Haes, I. Moerman, R. Baets and M.K. Smit

Indexing terms: Optical waveguides, Optical waveguide components, Lenses

A new waveguide focusing and collimating element which uses an elliptically shaped beam converter has been analysed and experimentally tested. The experimental results show good agreement with the designed values. These elements are index contrast insensitive and compact and only need simple waveguide technology.

Introduction: Waveguide beam focusing and collimating elements have been found useful in many applications in photonic integrated circuits. In wavelength division multiplexing (WDM) systems for example, a channel drop/add filter could be realised by using a collimated beam incident on a Bragg reflecting grating, and using focusing elements to collect the reflected and the transmitted beams. In this case a collimated beam realised in a planar waveguide is desirable. Expanded beam collimating elements also find applications in high power devices where they are used to reduce the power density at a facet. In the issue of light coupling between semiconductor waveguides and singlemode fibres, beam focusing elements could be used to reshape the optical field profile in the film plane to get an optimal overlap with the field of the fibre.

Optical beam focusing and collimating functions can in principle be realised by planar lenses [1], adiabatic tapers and curved mirrors. However, each of these structures has its drawbacks. If the waveguide lateral index contrast is low, a planar lens has a large focal distance and therefore requires a lot of space. If, conversely, the lateral index contrast is high, the diffraction losses at the lens boundary may be high. Adiabatic tapers have been widely used, but tend to be long [2, 3]. The curved mirrors require a perfectly vertical etch profile and therefore depend on sophisticated technology.

In this Letter we describe an elliptic beam converter which functions as a beam focusing or collimating element. It consists of an input waveguide followed by an elliptically shaped section and then a wide slab waveguide section, in which the wave can diffract freely in the lateral direction. The working principle of the device is based on total internal reflection at the boundary of the elliptic region, and can be understood by a three-Gaussian-beam model [4]. The input beam can be seen as a superposition of three approximately Gaussian beams: an axial beam, an upper and a lower beam. The upper and lower beam reflect off the upper and lower part of the elliptic converter, respectively, and are collimated or focused by it. The axial beam propagates with little impact from the elliptic coupler. In the slab region behind the couplers the three beams form an interference pattern, the shape of which can be controlled by the dimensions of the device.

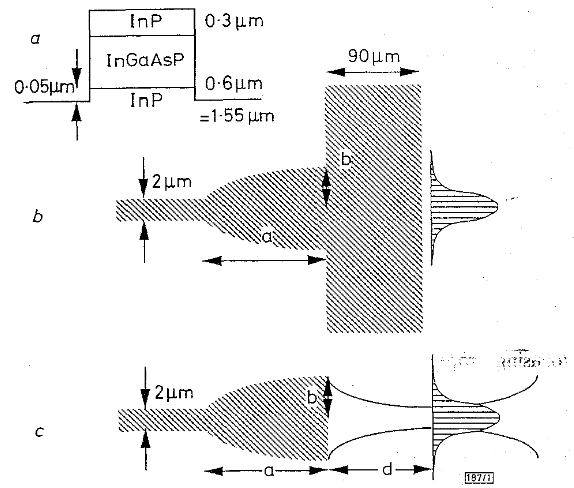

Fig. 1 *Schematic views*

a Waveguide cross section
b Ellipse structure with slab region
c Abruptly terminated ellipse structure

Design and experimental results: Simulations on the beam converting properties of different half ellipses, characterised by the ratio between the long and the short ellipse axes b/a (see Fig. 1), have been carried out using the 2–D finite difference beam propagation method. The effective index method was used to reduce the dimension of the transverse cross-section. If the b/a value is small, leading to a small angle between the upper and lower reflected beams, the interference pattern shows a collimated beam in the free space region. If, conversely, the b/a value is large, giving a larger angle between the upper and lower reflected beams, the interference pattern shows a focused beam in the free space region.

The waveguide cross-section used on the test chip consists of a 0.3μm InP upper cladding layer and a 0.6μm thick InGaAsP core layer grown on an InP substrate and is deeply etched through the guiding layer, see Fig. 1*a*. The operating wavelength is 1.55μm. The ellipse either ends on a semiconductor free space slab region with the same cross section as the ellipse (Fig. 1*b*), or ends directly on an air facet (Fig. 1*c*). The input waveguide is 2μm wide.

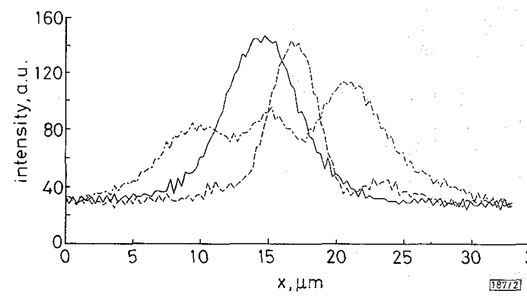

Fig. 2 *Field intensity at output of slab region (cf. Fig. 1b)*

——— coupler device with a = 150μm and b = 5.5μm
– – – – b = 6.5μm
–·–·–·– b = 7.0μm

The influence of the half axes lengths a and b of the ellipse on the FWHM of the output field at the output facet is analysed with the slab terminated structure of figure Fig. 1b. The a values were 150, 190 and 230µm and the b values range from 4.5 to 8.5µm with a 0.5µm step. The camera line-scanned intensity distributions show that the combinations (a, b) (150µm, 6.5µm), (190µm, 7.5µm) and (230µm, 8.0µm) have good focusing properties and small field side lobes at the output facets. The focusing ability degrades for smaller b values. Instead the element starts to act as a collimating device. In Fig. 2 measurement results are shown for a = 150µm and for three different b values, 5.5, 6.5 and 7.0µm.

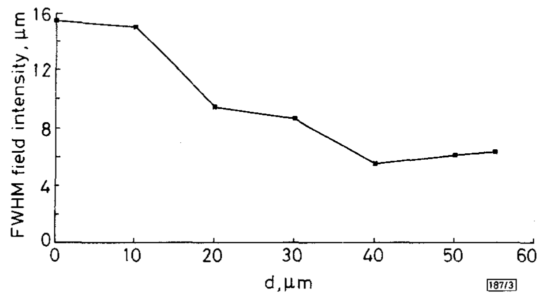

Fig. 3 *Beam waist (FWHM) of intensity against propagated distance in air for structure of Fig. 1c*

Measurements were performed for a device with a = 230µm and b = 8.0µm

The ellipses with air facets (Fig. 1c) are used to measure the field evolution in air after propagation through the ellipse. Different a and b values have been tested and the measurement results are in good agreement with the simulations. In Fig. 3 the beam focusing properties of a structure with a = 230µm and b = 8.0µm are shown. It is seen that the beam waist in a lateral direction, characterised by the FWHM of the intensity profile, is indeed evolving from a larger to a smaller value and vice versa along the beam propagation direction. Therefore, if the half axes lengths of the ellipse are properly selected, it is possible to obtain a desired beam waist at a certain distance outside the chip. Moreover, a larger collimated beam width or a longer focusing distance is achievable.

Conclusion: A new waveguide focusing and collimating element has been analysed and experimentally tested. The experimental results show good agreement with the simulated values. The structure is lateral contrast insensitive and compact and can be made with simple waveguide technology. Those elements can be used in acousto-optic waveguide to fibre coupling and in WDM elements where the optical field needs to be focused or collimated.

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References

1 VERDIELL, J.-M., NEWKIRK, M.A., KOCH, T.L., GNALL, R.P., KOREN, U., MILLER, B.I., and BUHL, L.L.: 'Aspheric waveguide lenses for photonic integrated circuits', *Appl. Phys. Lett.*, 1993, **62**, (8), pp. 808–810

2 LOVE, J.D., HENRY, W.M., STEWART, W.J., BLACK, R.J., LACROIX, S., and GONTHIER, F.: 'Tapered single-mode fibres and devices, part 1: adiabacity criteria', *IEE Proc. Optoelectron.*, 1991, **138**, (5), pp. 343–354

3 DUPORT, I.S., BENECH, P., and RIMET, R.: 'Optimisation of a collimation structure made by ion-exchange on glass'. European Conf. Integrated Optics, 1993, (Neuchâtel), pp. 14-42–14-43

4 WEI, C., HAES, J., DOBBELAERE, G., DEMEESTER, P., BAETS, R., LEIJTENS, X.J.M., DE VREEDE, A.H., SMIT, M.K., and METAAL, E.G.: 'Elliptic beam converters on InP: design and experiment'. European Conf. Integrated Optics, 1995, (Delft), pp. 193–196

Fabrication of single-mode polymeric optical waveguides by laser-beam writing

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Indexing terms: Optical waveguides, Optical polymers

A laser-beam writing system is developed for large-area optical waveguide fabrication. Single-mode embedded channel optical waveguides are successfully fabricated on both 4 and 8 in silicon substrates using deuterated fluoromethacrylate polymers by laser-beam writing in photoresist and dry etching. The propagation loss of the waveguides is as low as 0.1dB/cm at 1.3µm.

Recently, polymeric optical waveguides have attracted a lot of attention owing to their useful application in optical interconnections [1, 2]. Many kinds of board-level optical interconnections have been proposed [3–8]. Of these, one of the most attractive approaches is the fabrication of optical waveguides on printed circuit boards. This will require large-area optical waveguides with various patterns, because printed circuit boards are typically 20 – 30cm in length and have a variety of customised arrangements. However, conventional waveguide fabrication methods, in which channel waveguides are patterned using photomasks, cannot satisfy these requirements, because it is difficult to form such large photomasks with sufficiently high accuracy. For this sort of waveguide patterning, laser-beam writing [9, 10] is more suitable than conventional photolithographic techniques with photomasks. However, there have been few reports on singlemode polymeric waveguides fabricated by laser-beam writing, which would enhance the potential for the application of polymeric waveguides to optical interconnects. In this Letter, we describe a laser-beam writing system for large-area optical waveguide patterning and the fabrication of singlemode polymeric waveguides by laser-beam writing in photoresist and dry etching using deuterated fluoromethacrylate polymers [11].

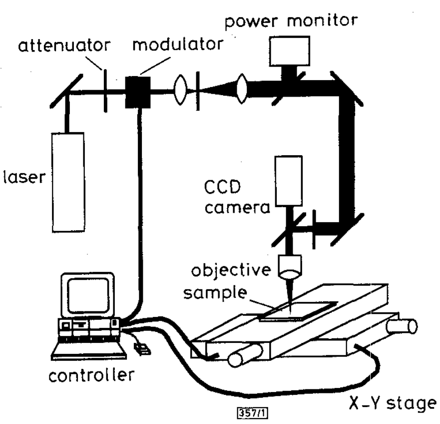

Fig. 1 *Configuration of laser-beam writing system*

The laser-beam writing system consists of a krypton ion laser (λ = 413nm), beam-shaping optics, an acoustooptic modulator (AOM) and an air-lubricated X-Y translation stage, as shown in Fig. 1. The AOM, which is synchronised with the movement of the stage, is used for switching the laser-beam on and off, and modulating its intensity. The air-lubricated X-Y translation stage, with a stroke of 300 × 200mm², is driven by DC motors and controlled in a closed loop by attaching laser interferometers to it so that its position can be detected instantaneously. The stage translation speed is continuously variable below 10mm/s. The position-