New two-port multimode interference reflectors

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Multi-mode interference reflectors (MIRs) are versatile components. Two new MIR designs with a fixed 50/50 reflection to transmission ratio are introduced. Measurements on these new devices and on devices similar to those in [1] are presented and compared to the design values. Measured losses are between 0.4 and 4.6dB. The measured power split ratio is in excellent agreement with the predicted split ratio of reflection and transmission.

integrated mirror; MIR; multimode interference; reflector

I. INTRODUCTION

An integrated reflector that keeps transmitted light available on chip can be used to create an on-chip laser. This laser could then be used as light source in larger photonic integrated circuits.

In [1] we introduced two-port MMI reflectors (MIRs) that can provide both reflection and transmission on chip. They are fabrication tolerant and can be made in the same fabrication steps as deep-etched waveguides. The ease of fabrication is the main advantage of MIRs, when compared to distributed Bragg reflectors (DBRs). Measurements of the first two-port MIRs in [1] showed that they were working as expected, but still had relatively high losses. Here we present new measurements on similar devices, plus measurements on two new MIR types.

First we introduce the basic concept of the MIR. Then section III discusses the design of the measured devices. We then briefly describe the characterization methods. Section V presents the measurement results, before we conclude in section VI.

II. CONCEPT

Multimode interference reflectors (MIRs) are based on the same principles as multimode interference couplers (MMIs) [2]. The main difference between MIRs and MMIs is that the output waveguides have been replaced by mirrors. This is shown schematically in Figure 1. The mirrors can be low loss, as long as the critical angle for total internal reflection is sufficiently below 45 degrees. By tapering the multimode section of the MIR, the ratio between reflection and transmission can be set freely. This is similar to the effect in MMIs as first mentioned by Besse et al. in [3].

III. DEVICE DESIGN

The devices were designed for an indium phosphide waveguide layer stack of Oclaro ltd (UK). The core consists of multiple quantum wells, leading to an equivalent slab refractive index of 3.25. The lateral cladding was air, with index 1.0. As part of the European project PARADIGM, Oclaro provided foundry services to us.

Four different types of MIRs were designed. They are labeled type A, C, D and E. Type A is based upon a 2x2 MMI using paired interference. Type E is based on a 2x2 MMI using general interference. These two types are new kinds of MIRs. Both types have a fixed 50/50 R/T ratio. Figure 1a. shows the shape of these MIRs. Type C (Figure 1b.) and D have symmetric and asymmetric butterfly MMIs as underlying types respectively. For the last two types the transmission to reflection ratio can be chosen by tapering the MIR. The amount of tapering is indicated by the width deviation dW. The value of dW can be normalized by dividing by the base width W. A negative dW means the device is narrower in the middle.

Table I presents the design values for all the devices. To be able to compare the new results to those in [1], the width and normalized width deviation dW/W are the same. The lengths are slightly different to compensate for the difference in layer stacks. Improvements to the device model allowed for more accurate predictions of the split ratio as a function of dW/W, than presented in [1]. This resulted in reflection to transmission ratios ranging from 22%/78% to 92%/18%. The designs were optimized for TM. All devices had input waveguide widths Wwg of 2 um.

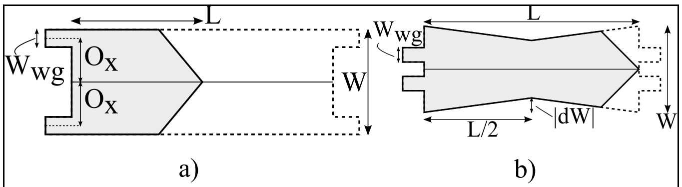

Figure 1. a) Schematic of an A/E type MIR (filled shape). The underlying MMI is dashed. For type A, Ox=W/6. For type E, Ox=(W-Wwg)/2. b) Schematic of a C type MIR (filled shape) based upon a butterfly MMI (dashed). Length L, width W, input waveguide width Wwg and width deviation dW.

IV. CHARACTERIZATION STRUCTURES

Two separate characterization structures were used for measuring the transmission and reflection of the devices. The first structure forms a Fabry-Pérot cavity out of two MIRs. The cavity has a fringed wavelength response. The reflectivity of the devices can be calculated from the ratio of the maximum and minimum of these fringes, provided cavity propagation losses are know or negligible.

TABLE I. MIR DESIGN VALUES AND MEASUREMENT RESULTS

ID *	W [um]	L [um]	dW/W	Rdesign [%]	*R* TE [%]	*T* TE [%]	*R* TM [%]	*T* TM [%]	Loss TE [dB]	Loss TM [dB]	Loss sim [dB]
A1	9.0	57.0	0.0000	50	30.9	41.7	34.3	41.9	1.4	1.2	0.7
C1	6.0	252.7	1.1869	22	5.5	51.4	3.1	54.2	2.5	2.4	1.0
C2	6.0	51.0	-0.1792	23	18.2	29.8	19.1	45.4	3.2	1.9	1.3
C3	6.0	65.4	-0.0849	36	20.0	29.7	29.2	44.5	3.0	1.3	1.1
C4	6.0	78.4	0.0000	50	28.6	29.4	38.9	32.7	2.4	1.5	1.0
C5	6.0	90.7	0.0849	63	36.4	24.6	44.6	30.3	2.2	1.3	0.9
C6	6.0	105.1	0.1792	77	43.7	9.1	42.9	22.0	2.8	1.9	0.9
C7	6.0	124.6	0.3119	92	40.8	4.7	30.1	5.0	3.4	4.6	0.9
D1	7.5	48.2	-0.2500	28	18.6	27.4	22.0	29.3	3.4	2.9	3.6
D2	7.5	67.8	-0.1500	50	20.3	20.5	37.3	32.8	3.9	1.5	1.5
D3	7.5	80.8	-0.0830	64	27.7	12.2	48.4	26.2	4.0	1.3	1.0
D4	7.5	96.8	0.0000	80	41.8	9.2	58.4	15.2	2.9	1.3	1.0
D5	7.5	110.3	0.0700	90	35.0	5.0	61.3	9.4	4.0	1.5	0.9
E1	5.0	54.4	0.0000	50	25.8	34.6	36.2	54.4	2.2	0.4	0.6

* input waveguide width is 2.0 um for all devices.

The second characterization structure uses a 1x2 MMI coupler to split the input power over a reference waveguide and a waveguide containing an MIR. The device transmission is then given by the difference in transmission between the reference and the device waveguide.

V. MEASUREMENT RESULTS

Using the characterization structures, described in the previous section, the power reflection *R* and power transmission *T* of the MIRs were measured for TE and TM polarization. Table I. lists the measurement results for all the devices. Device losses were calculated as:

$$\text{Loss}=-10\log(R+T)\ [\text{dB}]$$

When looking at Table I. it is clear that a large number of devices have less than 2 dB loss for TM. The devices were optimized for TM, which is why the losses for this polarization also match quite well with the values obtained from simulations. These predicted losses include the effect of a 3deg angle deviation of the mirror from perfectly vertical and imaging losses in the devices. Mirror roughness is not taken into account.

For TE polarization the device performs worse, with up to 3 dB polarization dependent loss. A more thorough inspection reveals that devices C1, C7 and D1 show relatively large losses. These devices also have the largest normalized width deviation dW/W. We assume that for these high taper angles mode conversion takes place and the imaging properties of the MIR start to break down.

Figure 2. shows that the normalized reflection coefficient of the fabricated devices match well with the design values. Notable exceptions are device C1 and D1. It is possible that mode conversion also plays a role here.

The losses presented in [1], corresponding to devices C2 through D7, ranged from 4.7 to 7.9 dB. Similar designs presented here have losses ranging from 1.2 to 4.6 dB. The two new MIR types show losses of 1.2 dB and 0.4 dB for types A and E respectively.

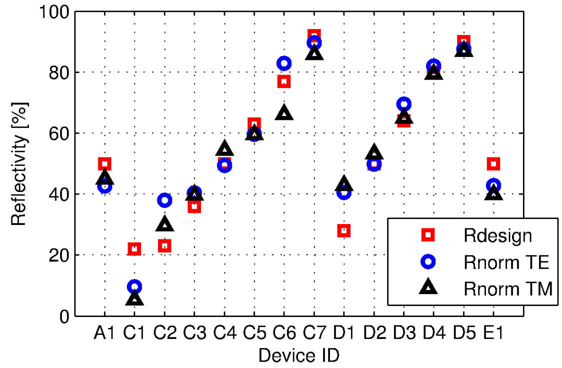

Figure 2. Normalized reflection coefficients (Rnorm = R/(R+T)) and design coefficients for TE and TM versus device ID.

TABLE II. BEST DEVICE CHOICE

Split ratio R/(R+T)	Criterion	Best device choice
< 20	Loss	C*
20 – 30	Loss	C
30 – 65	Loss	C or D
50,	Pol. Dependence	A
50	Loss	E
>65	Loss	D

*Does not agree well with simulation. When designing for ratios <20%, characterization is necessary.

VI. CONCLUSION

Two new MIR types were presented that show the lowest losses measured so far. The other measured devices show considerably lower losses than reported before. Furthermore, for type C and D, the ratio between reflection and transmission can be well controlled by tapering the MIR. Which device type to use depends on the requirements of the application, as shown in Table II.

MIRs can be fabricated in processes supporting deep-etched waveguides without making any changes to the process. Together with the measured low loss operation this leads us to conclude that MIRs are a valuable addition to existing components in photonic integrated circuits.

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