IECO-R5-084: Design and Fabrication of Polymer-Based Asymmetric Waveguide Coupler Utilizing Injection Moulding Process

Fadhlur Rahman Mohd Romlay[1,*], Mohd Shafiq Mat Ghazali[2,], Luqman Ismail[2]**

[1]Faculty of Mechanical Engineering Universiti Malaysia Pahang, 26600 Pekan, Pahang
[2]Nxphotonics Sdn. Bhd. 19-Mezzanine, Jalan Hentian 3, Pusat Hentian Kajang, 43000 Kajang, Selangor, Malaysia

*Corresponding author: fadhlur@ump.edu.my
**Partner: shafiq@nxphotonics.com

Abstract

Manufacture the plastic optical fiber (POF) is the key issue in this technology transfer program. Accelerate the manufacturing process of POF is the objective in this program. The design and modelling of an asymmetric waveguide couplers based on optical glue Epoxy OG142 is presented. The design of the asymmetric coupler is based on asymmetric Y-junction splitter using tap-off ratio (TOFR) technique. This asymmetric design was achieved by varying the size of the tap line while the bus line was fixed at 1 mm size. A Y-branch and the 1x2 asymmetric couplers with different taper sizes have been designed using CAD tool and ray traced using non-sequential ray tracing. Plastic injection moulding procedure as the knowledge transfer methodology set is set up to manufacture the coupler. The designed TOFR for the 1x2 asymmetric coupler varies from 23% to 50% for tap line width of 300 um to 1000 um. Ray tracing models of various coupler designs showed a linear relationship between the tap-off ratio (TOFR) and the waveguide tap width.

Keywords: *Asymmetric, Plastic Optical Fiber, POF, Tap-Off-Ratio, TOFR, Waveguide Coupler, Y-Branch*

1. Introduction

The use of plastic optical fiber (POF) as a medium for optical data communication is well known due to its highly large-core size, multimode properties, low cost and robust characteristics. Waveguide-based POF devices research are limited due to the fact that highly multimode devices have a smaller market especially for data communication application due to the high attenuation of POF compare to that of glass optical fiber [1]. Compare to the single mode glass fiber with an attenuation of 0.2 dB/km at 1550 nm, POF attenuation reaches 100 dB/km at 520 nm [2]. In sensor applications, POF has established wide use in multimode intensity-based sensor [3]. Some application examples of the intensity-based measurements POF sensors are detection of variation in liquid level, detection of liquid nitrogen level, temperature sensing [3], crack monitoring [4], monitoring dynamic response of fiber composite beam [5], and automobile sensor [6].

Optical sensing sometimes will require the passive optical devices to be designed with non-symmetrical branching arm. An asymmetric POF waveguide coupler has been widely ventured and used, recently by researchers for a generating a unique series of optical power for code generation in an optical access-card system. The device is based on the 1x4 asymmetric waveguide coupler with hollow structure [7]. The design of the metallic hollow waveguide structure is based on the concept of light propagation along the waveguide solely by reflection on the metallic inner-surface.

In this paper, the design and simulation of polymer-based 1x2 asymmetric waveguide coupler to be used as an optical code generating device in an optical access-card system. The design is based on plastic PMMA or acrylic substrate with an optically clear polymer used as the waveguide core. The design of the device is based on the cascaded combination of a 1x2 Y-branch coupler and two asymmetric couplers. The waveguide core material will be based on epoxy resin Epotek OG142 material. The device design and simulation using ray tracing will be presented.

2. Device Design

The 1x2 Y-branch coupler will enable the input optical power to be divided at 50% of the input power. Figure 1 shows the 2D layout of the Y-branch coupler designs used.

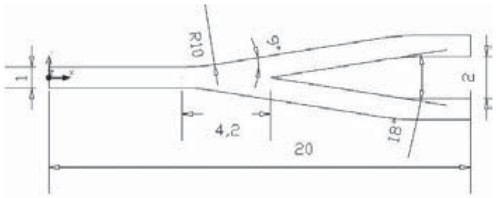

Figure 1. 1x2 POF coupler designs with 18º splitting angle and branching radius of 10 mm [8]

The design of 1x2 asymmetric coupler is based on a simple Tap Off Ratio (TOFR) technique to tap off power from the main bus line [8,9]. Fig. 2 shows a 1x2 asymmetric Y-junction splitter with bus and tap lines and a splitting angle of 18° [8]. In order for the tap line with smaller core size to be coupled to a larger core POF cable, a linear taper structure has been included at the end of the tap line.

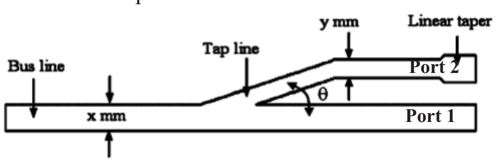

Figure 2. 1x2 polymer waveguide coupler design with different tap line (y) and bus line (x) [8].

The 1x2 asymmetric coupler utilized the concept of TOFR where a simple power tap can be achieved. The concept of TOFR is based on the asymmetric Y-junction splitter shown in Fig. 3 where the optical power in the bus line will be larger than that of the tap line. This is achieved by having the size of the tap line (port 2) to be smaller compare to the bus line (port 1). The TOFR or the ratio of the power exiting through port 2 to the total power incident in the bus line (port 1) is given by equation below [9]. By changing the taper line width, several combinations of the output power can be generated. The size of the bus line is set at 1 mm.

$$TOFR = \frac{y}{y+x} \quad (1)$$

The 1x4 asymmetric waveguide coupler can be easily constructed by utilizing the preceding 1x2 Y-branch and two 1x2 asymmetric waveguide couplers. A 1x2 Y-branch coupler is cascaded with two 1x2 asymmetric couplers. The Y-branch coupler will provide a 50% power splitting at the output port as shown in Fig. 3.

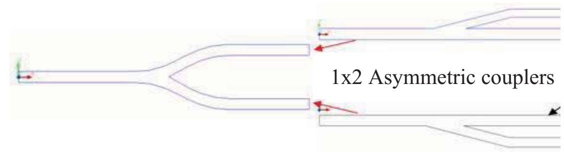

Figure 3. Higher-level waveguide design (a) 1x2 Y-branch coupler before joining with two asymmetric 1x2 couplers.

3. Injection Moulding Process

The coupler is manufactured using acrylic material utilizing injection moulding process. The coupler mould is designed using Solidworks CAD software for 3dimensional geometry specification as shown in Fig. 4 below.

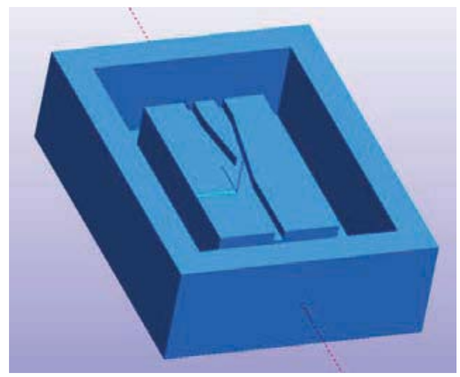

Figure 4: 3 dimensional CAD design of top mould insert coupler.

The mould design is based on TTE5 injection moulding machine and the specifications are listed Table 1 below.

Table 1: Injection moulding machine specification

Specification/Machine	TTE5
Maximum Clamping force	50 kN
Mould Opening Force	35 kN
Tie Bar Clearance (h x v)	V 82 mm H 165 mm
Platen Dimension	V180 mm H 260 mm
Ejector Force	15 kN
Ejector Stroke	20 mm
Dimension (LxWxH)	L1120mm W550mm H850mm
Weight	125 kg

Fig. 5 shows the cross section of the top mould insert that prepare by CNC machining process while Fig.6 shows the complete set of the mould component for plastic injection moulding process.

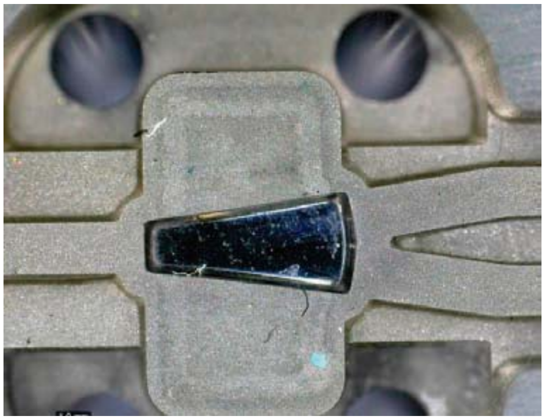

Figure 5: Machined top mould of the insert for injection moulding process.

Figure 6: Plactic injection mould set of the POF coupler.

4. Result and Discussion

In this paper, the design and simulation of the 1x2 and 1x4 asymmetric waveguide couplers with different TOFR are shown. Simulation of the waveguide coupler has been performed using non-sequential ray tracing technique. The wavelength used in this simulation is 650 nm, with an input power of 1.0 mW. Fig. 8 shows the raw product of the POF coupler by plastic injection process.

Figure 8. Cross section view of the waveguide coupler with the core and cladding properties

In the 1x2 asymmetric waveguide coupler design and simulation, the values for the tap width are set from 300 um up to 1 mm which provide TOFR of 23% until 50%. The design TOFR values with the tap line width of 300 um to 1 mm is obtained using equation (1) where the tap width are varied while the bus line is set at 1 mm.

Fig. 7 shows the plot of the TOFR against the tap width for both the designed and simulated devices. The result of TOFR for the designed device are based on equation (1), for y= 300 um until y=1000 um with a fixed bus line width, x of 1000 um. The simulated waveguide coupler shows the same linear characteristics as that of the designed. The simulated TOFR obtained for the 1x2 asymmetric waveguide coupler is from 21.0 to 49.9%.

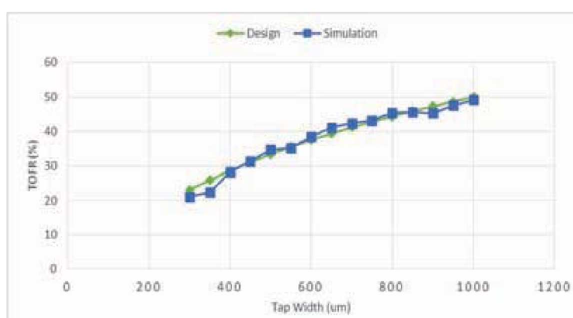

Figure 7. TOFR vs Tap width for 1x2 asymmetric coupler (design and simulation)

5. Conclusion

The design and simulation of 1x2 polymer-based asymmetric waveguide couplers for an optical access-card system are presented. The asymmetric coupler has been proposed to function as an optical code generating device. The waveguide devices are based on optical epoxy OG142 glue as the core material and PMMA material as the cladding/substrate. Non sequential ray tracing of the polymer waveguide coupler has been performed to characterize the optical performance of the device. The results shows there is a linear relationship between the output TOFR and the waveguide tap line width.

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