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Cost-Effective Fabrication of Self-Made 1×12 Polymer Optical Fiber-Based Optical Splitters for Automotive Application

Mohammad Syuhaimi Ab-Rahman, Hadi Guna, Mohd Hazwan Harun,
Saiful Dzulkefly Zan and Kasmiran Jumari
Department of Electrical, Electronic and Systems Engineering,
Faculty of Engineering and Built Environment, University Kebangsaan Malaysia,
43600 UKM Bangi, Selangor, Malaysia

Abstract: Problem statement: Multimode fiber cables can conduct many light rays and can operate free of disruption and with a greater bandwidth than a wireless connection. However, due to a slight variation in the speed of the light rays through the multimode fiber, a signal transmitted by all of these rays becomes spread out. Consequently, the signals become broader and therefore fewer signals fit in the fiber, limiting the transmission capacity. These demands grow almost daily. Hence new ways of splitting methods must be found to satisfy all application demands, especially related to automotive application. **Approach:** Home-made 1×12 optical splitter based on polymer optical fiber material base is one of the most innovative technologies on optical component which can be applied on some useful application. A perform technique had been used to fabricate kind of splitter. In order to develop such an efficient optical device which can be integrated into the body of automotive field, research with a good specification-oriented study tent to be conduct and it must be passed through a well-planned fabrication technique together with a proper characterization process. Multimode Step-Index Polymer Optical Fiber (SI-POF) type made of polymethyl methacrylate (PMMA) with $Ø_{core}$ = 1 mm and NA: 0.50 fully utilized in this research, as PMMA is one of the most commonly used optical materials. This material has been chosen as a base of splitter body in a fused-taper-twisted shape, produced by a unique fabrication stages. PMMA-POF can easily be used near it operating temperature between -40°C to +115°C. **Results:** By injecting 650 nm wavelength of red LED, characterization process start plays an important role in investigating level of efficiency of the device. Some parameters, such as optical output power and power losses on the devices were observed. Although the maximum output power efficiency of the splitter is about 40% but it can be improved gradually through experience and practice. **Conclusion:** The fabrication process is simple, easy and suitable to be used by household. Moreover, the users can determine the size of the fabricated device themselves. The POF-based optical 1×12 splitter had been suggested to be applied into automobile application to overcome blind spot area tracking problem as a one of low-cost solution in the future and also in home networking to avoid the bottleneck occurs between ONU and electronic appliances, resulting increase the speedy of data communication.

Key words: Polymer optical fiber, plastic optical fiber, POF, hand-made coupler, step-index, SI, polymethyl methacrylate, PMMA

INTRODUCTION

In the past few years, number of applications in automobile technologies based on optical fiber so rapidly developed as in the area of optical short-range communication. Demand POFs in application of automobile technology was relatively high[1,3-7]. POFs have attracted much attention in past decades especially in automobile field because POFs have some unique characteristics, such as flexibility, easy to handle, relative low cost in coupling due to their large core diameter[14-17], heat-proof, immune for noise (external electromagnet disruption), suitable for data communication for long distance up to 100 m, high speed data transmission (400 Mbps for SI's type and 1 Gbps for GI's type), higher bandwidth (exceed 4 GHz)

Corresponding Author: Mohammad Syuhaimi Ab-Rahman, Department of Electrical, Electronic and Systems Engineering, Computer and Network Security Research Group, Faculty of Engineering and Built Environment, University Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia

and have losses below 25 dB km^{-1} additional loss once it bent[3,4,5,7]. In vehicles, airplanes and rail transportation more and more digital communications connections are being utilized[4]. As a result, increased demands on the architecture of the data connections as well as the transmission media are being made[1].

Due to fact, that automobile field the step towards digitalization has long been made, POFs can meet many of these requirements to an optimum degree and are therefore increasingly of interest. Likewise, in the automotive technologies based on passive night vision, POFs can be applied to support these systems. Proposed study for passive night vision was defined by passive imaging system based on optical fiber sensor application. This sensor application was kind of technology based on optoelectronic and optical data communication through optical fiber. Optical fiber sensor gave more advantages compared with electronic sensor due to it quality, high sensitivity, high-speed data rate, low power budget and low cost components required[6].

Optical imaging through optical fiber defined as a light transmitting system which being reflected by one of an end of optical fiber to another. This process will be successfully worked once a source of light applied on it, triggered the switching speed, with an appropriate wavelength and high optical output power. It is called passive system; they used the surrounding light as source to lighten up focused objects.

In the context of automotive or driving, the particular invisible area by the driver either from forward direction or backward called blind spot area. Tracking over blind spot area focused on the behind part of vehicle, because while driving, the attention of the driver was more focused on forward area and the eyesight range of behind vehicle was less.

Many research come out with their own proposed technology have been carried out, start from conventional side mirror (Fig. 1) until costly advanced ultrasonic sensor which put in the bumper part of vehicle. Although various methods were introduced to track blind spot area yet respectively has distinctive weakness. Therefore, further study need to be developed to solve the blind spot area tracking problem and overcome the weakness of previous methods.

Passive night vision with POF-based technology expected to be able to compete with other previous method to overcome the blind spot area tracking problem. Study for characteristics of POFs was strictly required to conduct for achieving desired design with some detail modification. In this case, the proposed fabrication design finally comes out with a real fused-taper-twisted POF splitter (Fig. 2). The existing optical splitter made from waveguide based has been fabricated in full-equipped laboratory with the cost for each unit is approximately more than 1000 USD (1:12 ratio). As compare with our self-fabricated POF device which the cost is less than 10 USD. The customer themselves can fabricate the device with simple apparatus set up.

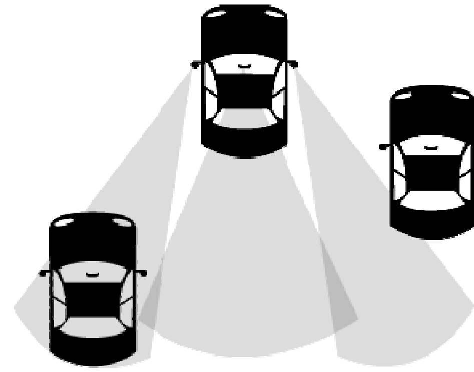


Fig. 1: Blind spot area tracking with conventional side and rear-view mirror

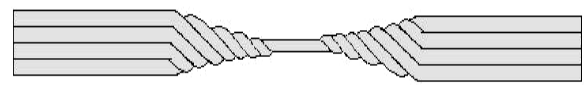


Fig. 2: Fabrication of fused-taper-twisted POF

In this study, as a preliminary work on the investigation of prototype characterization, it also carried out to develop the design of end part of fused-taper-twisted POF splitter. In prototype characterization, some experiments were conducted to determine optical output power, POFs attenuation characteristics and power losses on the network. We propose 12×1 POF optical splitter uses for passive night vision development. The edge of 4 groups fiber (buddle of 3 fibers together) are polished to capture effectively image of automotive back area with the assisting of nature sunlight (day used) and back lamp light (night used). With the signal processing for the further processing ensure the vision is clearly and attractively. But in this study we highlighted on the fabrication and characterization of 1×12 POF optical splitter which can be used as sensor in this application proposal.

MATERIALS AND METHODS

POF-based splitter is an optical device which ended by 12 POFs, while the other side ended by 1 POF. Furthermore, they both work bidirectional. However, they can work from the 1 POF into 12 POF or vice versa, for passive night vision application we need to apply splitter function which operated from 12 POF combined into 1 POF, based on the objective of the research to ensure 12 separate optical signals to be linked into one coupled signal, as a centralized monitoring concept to overcome blind spot problem.

In development process of 1×12 splitter based on POF technology, multimode SI-POF type made of polymethyl methacrylate (PMMA) 1 mm core size fully utilized in this study, as PMMA is one of the most commonly used optical materials, Due to its intrinsic absorption loss mainly contributed by carbon-hydrogen stretching vibration in PMMA core POF[6]. Prototype development gives a priority in fabrication method due to expectation to generate an optical splitter with the specifications which meet research's requirement. Development process for the proposed technology can be shown in Fig. 3.

In this study, optical 1×12 splitter developed by the jointing of Optical 1×3 splitter and Optical 1×4 (both devices fabricated based on fused-taper-twisted POF). Other specification for the design, the 1×12 splitter reach data transmission distance up to 25 cm. therefore, a POF cables (11-13 cm length) is required to be linked with end part of 1×3 splitter (as an output) to input of 1×4 splitter. Basically, this optical 1×12 splitter design (Fig. 4) formed by all four optical 1×3 splitters arranged in series and this series arrangement connected with optical 1×4 splitters parallel.

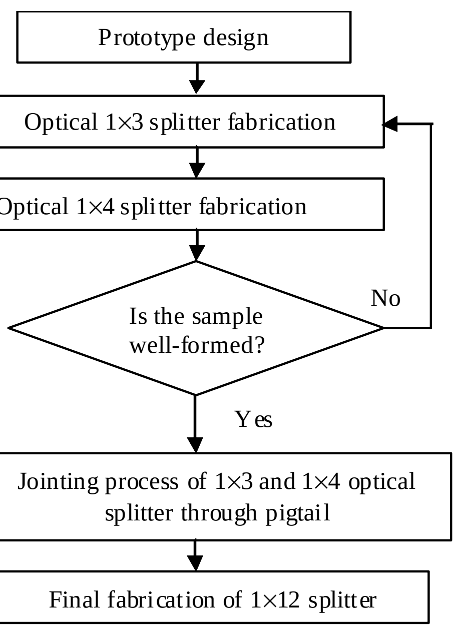


Fig. 3: Flowchart for prototype development process

To fabricate the final product of optical 1×12 splitter, some stages has to be done, start from fiber fusion, bundle formation and finalized with cable jointing. Fusion method either for optical 1×3 or 1×4 splitter has just the same principle. Fabricated through fusion method by fuses and combine 3 or 4 POFs (in bundle form) and fabricate it ends part in a shape of fused-taper-twisted fibers (diameter 1 mm). POFs will be twisted and pulled down while it is fused in a heat of flame. Heating process was done indirectly, while POFs covered by metal tube. Thus, heat was provided for POFs through metal tube heating (Fig. 5).

Right after twisted closely of POF's center part obtained, metal tube will heated up until center part starting melt. Than, gently pull the POFs in opposite direction, until the shape of that part getting taper-twisted.

However, some of the POFs successfully fabricated before, some damaged sample still found from the fabrication aspects of it, e.g., imperfect shape. A sample can be called ideal once its diameter uniformly fused-taper-twisted approaching 1 mm. To confirm that samples unable be used in characterization testing, these sample will be tested by red-LED injection.

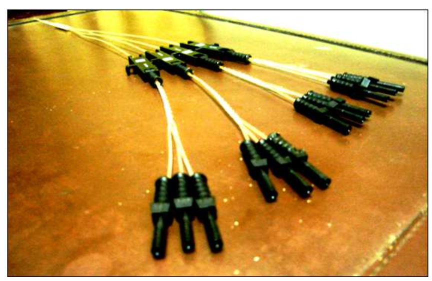


Fig. 4: Final product of **o**ptical 1×12 splitter for passive night vision application

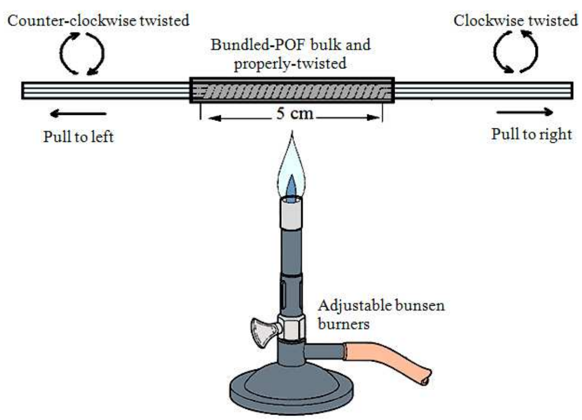
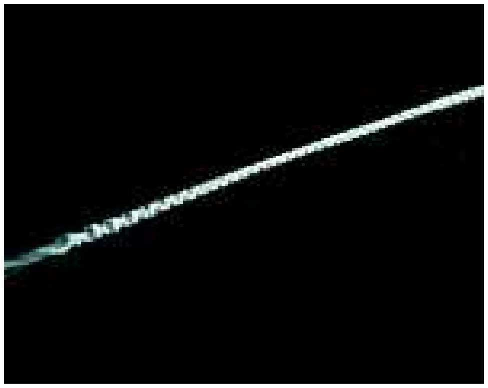


Fig. 5: Fabrication method of bundle POFs



(a)

(b)

Fig. 6: Final product of fused-taper-twisted POFs in (a): Well-formed and (b): Deformed shape

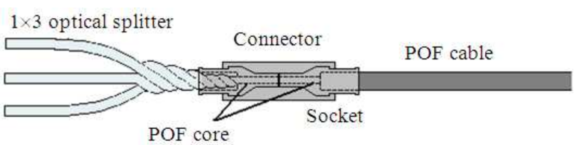


Fig. 7: Connection between optical 1×3 splitter with 1 mm POF cable

It is obtained that red-LED will not came out from the samples in a bad quality. Thus, the samples cannot be use in characterization testing (Fig. 6a and 6b).

To connect optical 1×3 and 1×4 splitter, research suggests using 1 mm POFs cable. Connection between 1×3 splitters and POFs cable joint by POFs connector (1 mm core diameter with jacket). POF connector contains two difference socket side, the one with a wide socket pit while other have a narrower. The end part of 1×3 taper-twisted POFs inserted into the socket with a wider slot and glued properly, so that the connection will be difficult to be pulled out. While the other slot side of connector inserted by POFs cable (Fig. 7).

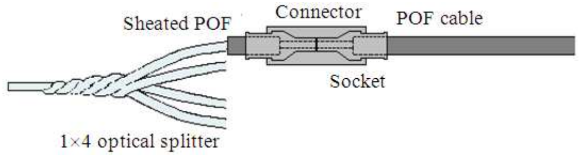


Fig. 8: Connection between 1×4 splitter with 1 mm POF cable

Fig. 9: Characterization process by utilizing 650 nm wavelength for red LED injected into bundle fiber to observed level of efficiency for each fiber

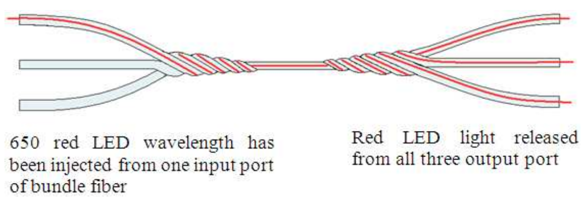


Fig. 10: Coupling method for the three optical coupled signal

After successfully linked the optical 1×3 splitter with one side of POFs cable, fabrication method continue by connecting the other side of POFs cable with optical 1×4 splitter with the same method explained before (Fig. 8).

In this study, characterization process need to be carried out for each fabricated optical splitter. Each of developed splitter must be able to coupling every optical signal to generate one coupled optical signal with low power loss. Optical power meter has been used to measure the optical power from POFs. Before the switch opened, it is obtained that 0.02 µW for it zero error exists on the meter. It is stated that 11 µW optical power of red LED was injected as an optical input power for each POFs (Fig. 9 and 10).

RESULTS

The best ten sample has been fabricated and each of them have to be pass through a characterization stages, which lead to observation on level of efficiency for each sample. Red LED with 650 nm wavelength has bees injected into the fibers, once the light through the fiber start from the input port to the output, surely caused a deviation on power of the light itself.

The analysis of the prototype characterization was carried out, especially for it efficiency percentage of each POFs. Hence the comparison for the all power efficiency of optical 1×12 splitter based on POFs has been observed, which the 1 end-POF act as an input and the other side which consist of 12 POFs stated as an output, the comparison between input and output has been calculated (Fig. 11).

From the observation above, the power efficiency of each output shows a different value with a maximum power efficiency reaching 40%. It is true; because error could be happen on it either while fabrication process or characterization test stages imposed on them. Average power of all samples shown in Fig. 12.

Irregularities of controlled heat while heating process exposed on the POFs become one of the major problem, due to it lower melting point makes core structure of POF could be more sensitive on heating process. Once it is damaged, it is hard to let a light pass through the core, or even not pass at all. According to Fig. 10, graph for the efficiency and power loss percentage of each sample can be obtained (Fig. 13).

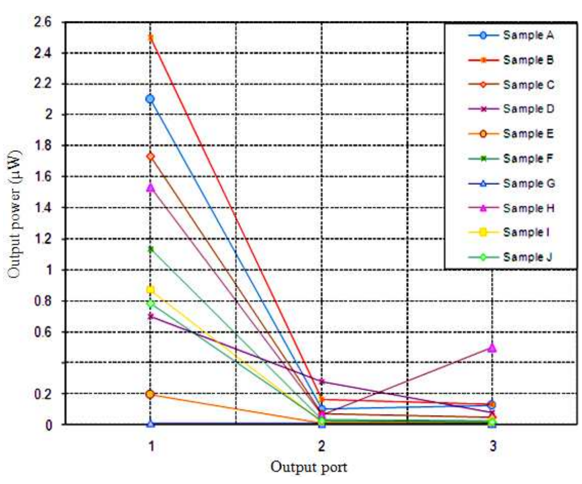


Fig. 11: Comparison of each POF output port which has been injected with 11μW from the input port (1POF), maximum efficiency of the splitter reach up to 40%

The result obtained as shown in Fig. 10, research still continue by choose the best four sample to check the level of power efficiency bidirectionally of 3×3 optical splitter. The purpose of this measurement is to check wheatear the coupling method is sufficient enough to be conduct on the device. Hence measurement and comparison for both port of 3×3 splitter need to be conduct as shown in Fig. 14.

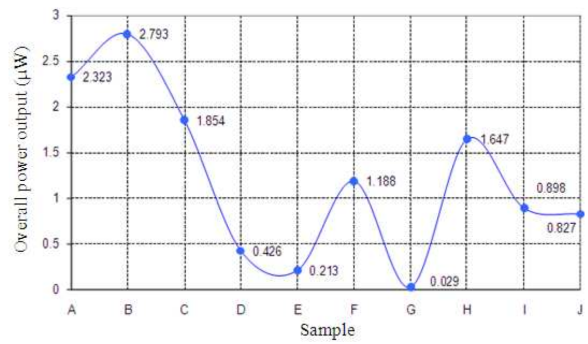


Fig. 12: Obtained power output compared with expected result

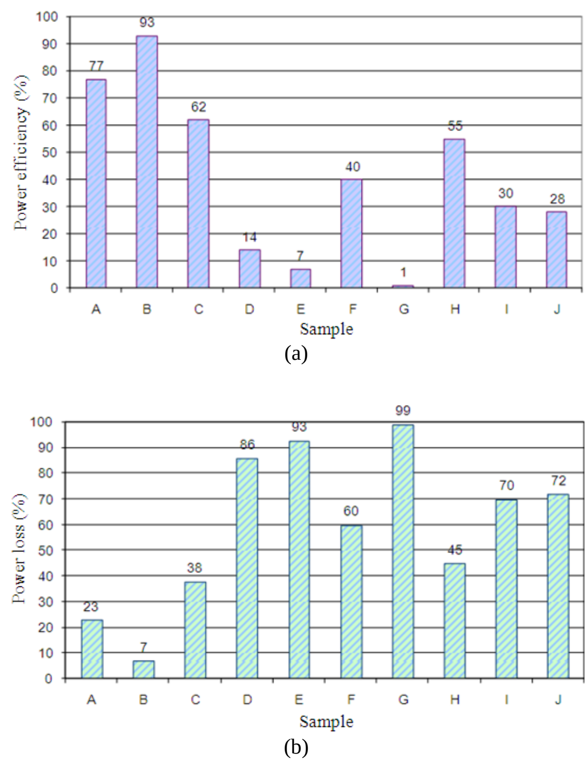
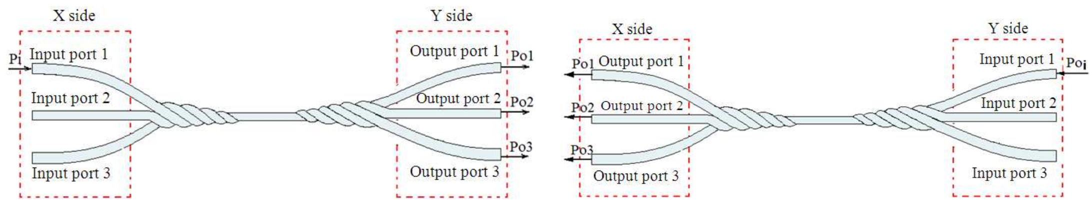
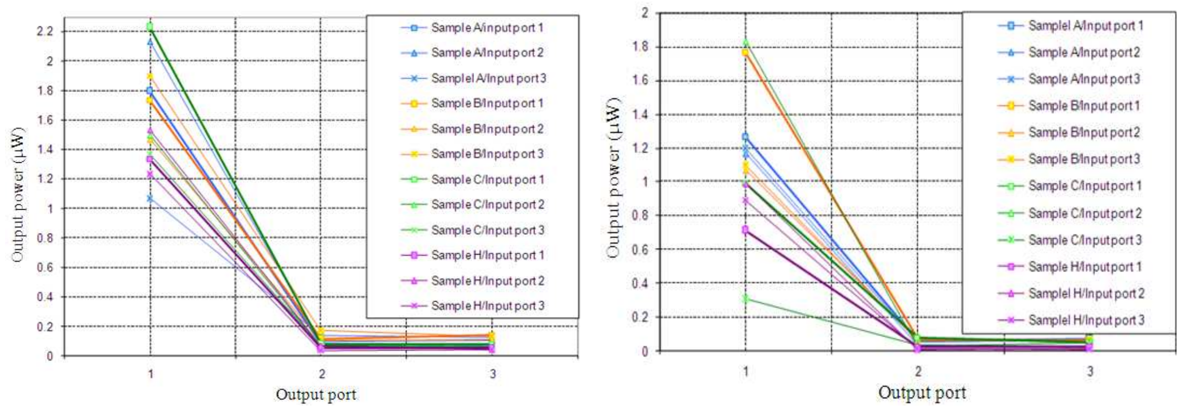


Fig. 13: Observation for power (a): Efficiency and (b): Loss for all samples



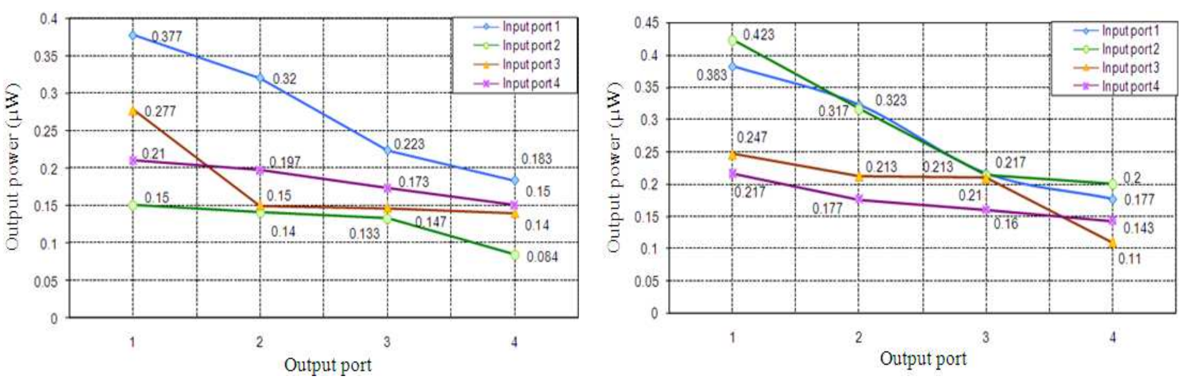
(a) (b)

Fig. 14: Bidirectional measurement test for 3×3 splitter from (a): X-Y side and (b): Y-X side



(a) (b)

Fig. 15: Observation on both sides of 3×3 bundle fiber for a purpose of comparison on efficiency of each port whether from (a): X-Y side and (b): Y-X side



(a) (b)

Fig. 16: Bidirectional test for 4×4 optical splitter from (a): X-Y side and (b): Y-X side

For this measurement stage, the best four samples which have been chosen are sample A, B, C and H which is have the highest level of power efficiency and will be injected with 3 µW input power measured by digital optical meter. Characterization process conducted twice and started with measure the light flow from the one input (X side) into the three output port (Y side) using power meter and otherwise. Result for the two measurement test can be observed in Fig. 15.

Bidirectional measurement test also conducted for 4×4 optical splitter, it is for testing whether both side of splitter has a significant deviation or not, in term of it power efficiency. Method of this measurement could refer to schematic diagram from Fig. 14 with a few different, it is from the number of the port, which for this stage the number of input and output port are four. Observation for this test can be shown in Fig. 16.

DISCUSSION

1×12 hand-made optical splitter based on Polymer Optical Fiber (POF) is one of innovative optical component which able to split a coupled signal in a such a way it can communicate bidirectionally from transmitter to receiver or otherwise. In order to develop a complete set of splitter, it is necessary to investigate the performance of it parts, consist of four units of 1×3 optical splitter and cascading them into one unit 1×4 optical splitter.

Before joint both splitter, first job must be done is choosing the right sample, so that all parts of splitter can transmit light as efficient as possible. While choosing the right sample, characterization process can be made upon each splitter. For example, in order to develop a complete set of 1×4 splitter, initially, we have to fabricate 4x4 optical splitter than we cut one of the side while just let the other side have four port, so that we get a 1×4 port bundled fiber. The problem here is how to choose the right side to be cut.

In this study, bidirectional test has been conduct to measure how efficient both port of bundled fiber before being cut one of the sides. After the efficiency level of each port has been obtained, decision to cut one of the sides will be made.

Result from best four samples of 1×3 optical splitter performance have been obtained, as we can se all of the three output port from splitter not release the same intensity of light from the three port. They just give one output port with the highest power, while the other two ports release a very low intensity of red LED light. Here shows that, coupling process does not efficiently work inside the body of bundled. Measurement test from X-Y side indicate that efficiency of power transmission approximately reach up to 80% efficiency with 3 μW initial power from injection of red LED. While, measurement conducts from the other side, from Y-X side, the meter just obtained 65% efficiency of the device. In conclusion, the deviation of two different ports is occurred, which X-Y power flow is 15% more efficient than Y-X.

While for 4x4 splitter, the best performance for the splitter able to reach 60% of power efficiency came from X-Y flow measurement, while the worst deviation between X-Y and Y-X measurement approximately 30% different. Here, X-Y power flow shows a better performance than it opposite. Many factors influence the deviation occurred from both side of splitter. Right after fusion process done, final result of the splitter should gain a differences in numerical aperture, remind that the device is a hand-made product, so the differences obviously happened. If the input fiber has a smaller aperture, the light is completely guided by the output fiber. However, if the NA of the output fiber is smaller, there will be some losses.

From the structure of bundled fiber itself, Rough surface here, due to a fusion and twisting process, also play an important role to bring some losses into the splitter. This changes the light path and part of the power is lost through diffraction or scattering. A specific problem of the rough surfaces is that the light does not necessarily have to be lost immediately at the coupling spot. Rather, a part of the light can be converted into large propagation angle. By means of mode-dependent attenuation it can then be lost little by little in the following centimeters. In conclusion, here still many factor possibly to explain which able to affect the efficiency of the splitter, due to the failure from fabrication process, but the main point here is the performance still can be improved gradually through experience and practice.

CONCLUSION

In summary, a fused-taper technique has been used to fabricate 1×12 optical splitter with based on POFs technology. Multimode SI-POF type with 1 mm core size fully utilized for the base material of the splitter. Some procedures, such as fabrication and characterization stages have been carried out to develop the splitter. Red LED with a 650 nm wavelength has been injected into the splitter for the purpose of characterization testing to analyze the level of power efficiency of the splitter. Final analysis shows that efficiency of splitter output able to reach up to 40%.

This POF-based optical 1×12 splitter have been suggested to be applied into automobile application to overcome blind spot area tracking problem as a one of low-cost solution in the future. As advised, POF sensor will be connected with optical 1×12 splitter, in this case the splitter will be act like an optical network which has a function to coupling the optical signal (blind spot area image) from all of installed POF to become one coupled signals (12×1) to be sent into POF transceiver (for optical signal processing). It is recommended to install all of 12 POF sensors into the bumper back side of vehicle, in order to obtained wider imaging (blind spot) area.

Further study about interfacing POF-based system for the automobile application are advised to be conducted, all the way to improve the efficiency of POFs power transmission, in order to overcome blind spot area tracking problem with passive night vision application.

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