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Low-cost Cascaded 1x4 Polymer Optical Fiber Coupler for Multiplexing Wavelengths

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Abstract— **The Wavelength Division Multiplexing (WDM) technology considered as the only solution for increasing demand for higher bandwidth in optical communication, whereby several different wavelengths can carry variety information over one Polymer Optical Fiber (POF). Wavelength Division Multiplexer is an essential component to combine several different wavelengths before all wavelengths are carried together over single POF. In most instances, the conventional multiplexers are afflicted with certain disadvantages and one major disadvantage is that they are costly for most of the POF applications. Thus, the goal of this study is to develop self-fabricated POF coupler as an economical optical multiplexer for WDM transmission over POF. The POF coupler has been fabricated by homemade fusion technique. Red LED with a 650 nm wavelength has been injected into the coupler for the purpose of characterization testing to analyze the level of power efficiency of the coupler. The characterization of POF coupler reveals that the maximum power efficiency could be reached up to 70%. The result exhibits that self-fabricated 1x4 POF coupler has great potential to be applied as optical multiplexer for WDM fiber technology due to the character of high-efficiency and low-cost**.

Keywords— polymer optical fiber (POF), coupler, fusion technique, wavelengths division multiplexing (WDM), multiplexer.

I. INTRODUCTION

The demands for Plastic Optical Fiber (POF) in application of communication was relatively high [5.9], due to some characteristics strength of it, such as flexibility, easy to handle, relative low cost in coupling due to their large core diameter [4], heat-proof, immune for noise (external electromagnet disruption), suitable for data communication for long distance up to 100 meter, high speed data transmission (400 Mbps for SI's type and 1 Gbps for GI's type), higher bandwidth (exceed 4 GHz) and have losses below 25 db / km additional loss once it bent [4,5,9]. Due to advantages of POF highlighted above, major communication systems over copper wire or even silica fiber has been replaced with POF.

As communication systems via POF demands for very high capacity long distance transmission systems due to the rapid growth in use of phones, faxes, computer networks, and the internet, fiber capacity will have to keep pace. One promising attempt is to carry many wavelengths to convey high bandwidth of data via optical fiber [1,3]. This technique is called Wavelength Division Multiplexing (WDM). Because of the dramatic increase in capacity of optical communication using WDM, there has been an increasing interest in the development of particular devices to manage a number of wavelengths.

Multiple transmitters with different lights color represent different wavelengths used to carry individual information. For example, red light with 360nm wavelength modulated with Ethernet signal while blue, green, and yellow light carry image information, radio frequency (RF), and television signal respectively. All wavelengths are carried simultaneously over one single optical fiber. Hence there is no limitation in bandwidth for optical fiber using WDM. But two new parts must be integrated in the communication system [3]. The first is the multiplexer that must be placed before the fiber to integrate every wavelength to a single waveguide. The second component, the de-multiplexer, is placed after the fiber to regain every discrete wavelength. This technology has the power to master the bandwidth requirements, which are needed to provide new multimedia applications in various fields of life [1,2,3].

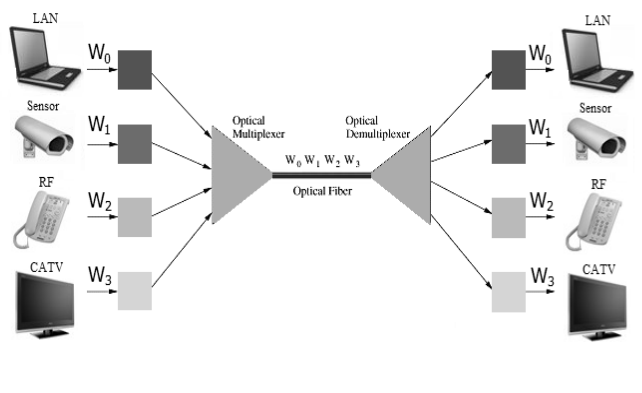

Figure 1 POF coupler as multiplexer and de-multiplexer in WDM- POF

Conceptually, multiplexers work to mix several different wavelengths together in order to directing all wavelengths through single fiber while fiber coupler may perform similar function. Thus, fiber coupler is applicable to be multiplexer. The conventional multiplexer based on silica fiber afflicted with some major disadvantages, whereby it is highly expensive due to silica fiber itself. Furthermore, the use of active laser is vulnerable to risk of eye damage. As POF is more favorable than silica fiber is, POF has been employed as base material to fabricate passive device such as splitter, coupler and sensors.

Since years ago, there have been many types of POF coupler fabricated for commercial purpose. Yet, they are totally not cost-effective as well as they are priced at roughly up to 200 USD in global market. The price is verily not worth it as there is great deviation between product price and original price of single POF itself. The high cost manufacturing concerned as main reason for dramatic high cost, whereby the costly full-set sophisticated machine used to fabricate POF coupler commercially.

In this study, fusion technique is practically applied to fabricate POF coupler. Essentially, the term of 'fusion' defines the act or procedure of liquefying or melting by the application of heat [2]. The fusion technique has been practiced using sophisticated machine particularly for POF fabrication. In order to develop the economical POF coupler, this study is also undertaken to modify the typical fusion technique, whereby the technique is just fully implemented by handwork. The heating elements and immune-to-heat tube (from the previous fusion technique) are changed in terms of availability and the appropriate twisting and pulling strengths are tuned in order to fuse all POFs [3, 6]. Furthermore, the characterization of the self-fabricated 1x4 POF coupler is carried out in order to determine the performance of developed device.

II. Experimental

The developed POF coupler is passive device with four POF inputs combined and fused in the middle part, then ended by single POF output. This device works bidirectional, from the 4 to 1 POF or vice versa. For the purpose of multiplexing several different wavelengths, the device preferably operates from 4 to 1 port. Through fused taper POF, four different wavelengths will be combined, and then multiplexed signal carried along POF output.

1. Materials

In development process of 1x3 coupler based on POF technology, 1 mm core diameter polymethyl methacrylate (PMMA) based POF with multimode step index profile and fluorinated cladding fully utilized for our research, 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 while fluorinated polymer permit delivering optical signal with lower attenuation [10].

2. Prototype Design

In relation with the purpose of multiplexing wavelengths, the 1x4 coupler's output designed to have fused taper-twisted shape. The other specification is that every single of inputs and an output all are connected to 11-13 cm POF cable via connector (see figure 2).

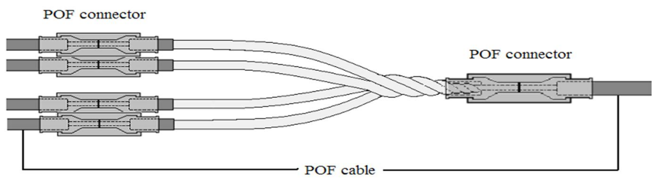

Figure 2 The deisgn of 1x4 POF coupler

4. Fabrication Method

In order to fabricate the cascaded 1x4 coupler, the processes include bundle formation, fiber fusion and lastly, cable jointing. The POFs fusion aims to fuse and combine four POFs (in bundle arrangement) and to fabricate fused taper-twisted fibers along the middle of POF bundle whereby the diameter of this part is symmetrically decreasing reach 1 mm. POFs will be twisted and pulled simultaneously while the fiber are fused in a heat of flame. Heating process was done indirectly, while all POFs covered by metal tube (see Figure 3). The fused bundle (specifically called as 4x4 coupler) is cut right at the center part in order to form 1x4 coupler. The fused bundle, however, is not yet ready to be cut as several characterization tests have to be done.

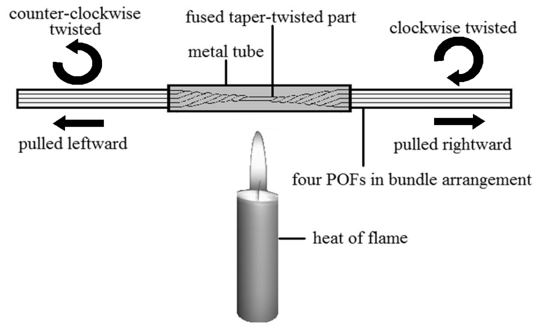

Figure 3 Fabrication method for fused-taper-twisted POFs

To connect POF with user and to make it longer, it is suggested to use 1 mm POFs cable with a length around 11-13 cm. Connection between 1x4 couplers 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 1x4 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 (see figure 4).

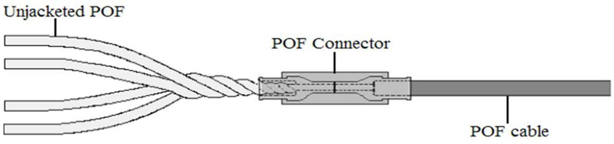

Figure 4 Connection of coupler's input and 1 mm POF cable

After successfully linked the optical 1x3 splitter for 1POF side, fabrication method continue by connecting the other 3POFs side with the same way explained before (see figure 5).

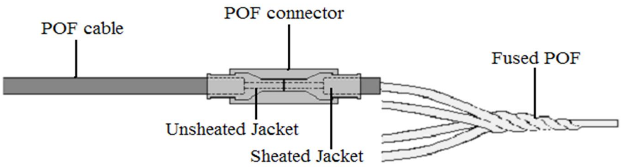

Figure 5 Connection of coupler's output and 1 mm POF cable

5. Prototype Characterization

In this study, characterization procedure needs to be carried out for fabricated POF coupler. The developed coupler must be able to properly coupling four optical signals in order to generate single multiplexed signal efficiently, with low power loss. Before the fused bundle (or 4x4 coupler) cut at the center part, the prototype is initially tested to determine whether it is able to couple optical signals. Physically, fused bundle consists of 4 outputs and 4 inputs. Red LED with 360 nm wavelength injected through one out of 4 inputs. The prototype is realized that be able coupling signals if only four POF outputs emit red light (see figure 6).

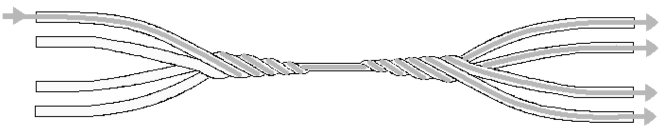

Figure 6 The procedure of fused bundle characterization

Optical power meter has been used to measure the optical power from POFs. Before the switch opened, it is obtained that 0.02mW for it zero error exists on the meter. Bidirectional optical loss measurement is carried out in order to determine either side of the 4x4 coupler with lower optical loss as final product of 1x4 coupler before cutting the middle of the 4x4 coupler. Red LED injected through each of inputs individually and separately from the right side (lights propagate leftward) in order to measures output powers and calculates the optical loss. Then, similar procedure is repeated for rightward measurement. Finally, the coupler's characteristic of optical loss in both directions analytically compared.

After cutting fused POF bundle (4x4 coupler) at center part, the performance of the 1x4 coupler is determine as the finishing for characterization processes. In order to measure the power efficiency of coupler, 12mW optical power of red LED is injected into single fused POF and each of four POFs inserted into optical power meter. Ideally, once the input power starting injected into optical 1x4 coupler, the output and input value will be the same. In this case, if we inject 12mW of optical input power, than the other end side of 4 POFs could be reach ~3mW of output power for each POF (see figure 7).

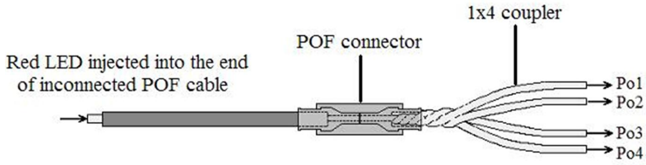

Figure 7 The procedure of 1x4 POF coupler characterization

III. Results and Discussion

Through modified fusion technique, the ideal sample of fused-taper-twisted POFs is successfully produced which the diameter of uniformly fused taper-twisted approaching 1 mm, As the result of injecting red LED through the sample, it is observed that red light pass directly through fused taper-twisted POFs. So this means that there is no deformation along fused taper-twisted POFs. After cutting the center of symmetrically fused taper-twisted POFs and jointing with POF connector, the cascaded 1x4 POF coupler successfully developed according to design specification (see figure 8).

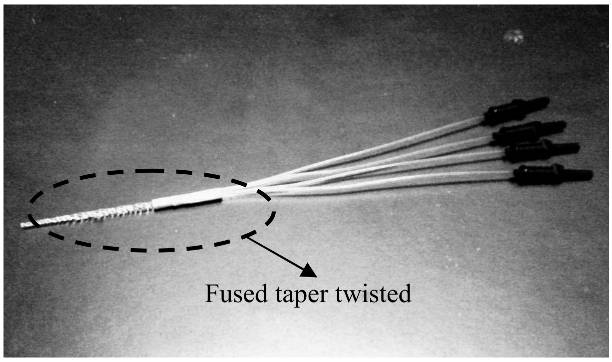

Figure 8 The feature of developed 1x4 POF coupler

The analysis of the prototype characterization has been carried out, especially for its characteristic of signal coupling, optical loss in fused POF bundle (in rightward and leftward direction), efficiency percentage of each POF outputs and overall power efficiency of the 1x4 coupler. As the characteristic of signal coupling observed, it is found that each individual output POFs emit red lights. Nevertheless, according to observation, the light intensity from each POF outputs is not equal. Of each output ports, three POFs exhibit high light intensity and another POF exhibits low light intensity (see figure 9).

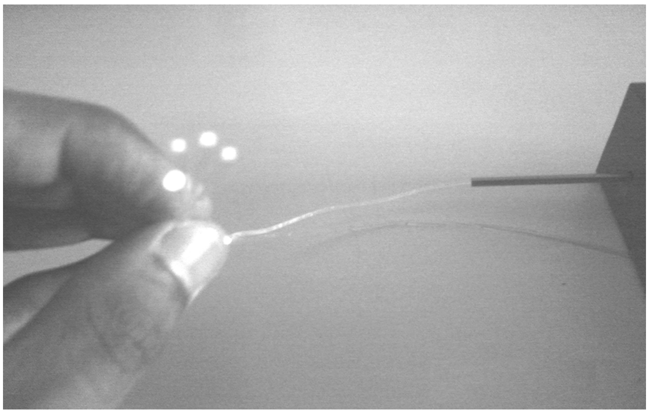

Figure 9 The observation that 4 POF ouputs of fused bundle's emit red light with different intensity

The observation reveal that fused bundle has ability of coupling signal as the light successfully divided into four separations through fused part where all POFs are merged together as single transmission media. The phenomenon that red light emitted from each POF port, valid that four individual optical signal merged as 4x1 signals. Ideally, the light will be separated with equal intensity, whereby the light intensity for each port is 25% of injected light. In this case, it happen if only all POFs in bundle are fused as well as the all mixed forming so-called one POF.

The characterization of fused fiber bundle has been performed right after determining its characteristic of signal coupling. By injecting red LED through each of POF inputs on both sides of fused bundle separately, the average optical loss for fused bundle in both leftward and rightward directions have been calculated and analytically compared (see Figure 10).

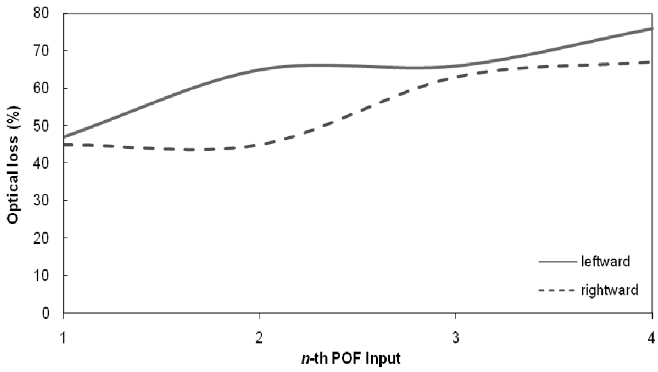

Figure 10 The analysis of optical loss for fused bundle in both direction.

According to the observation above, it is revealed that the efficiency of fused in different direction is not identical. Analytically, fused POF bundle has lower optical loss in rightward direction. Thus, the left side of fused POF bundle selected as POF coupler because it may couple multi optical signals and produce single optical signal with lower attenuation and higher efficiency compared to the other side. Optical loss for fused bundle caused by physical changes on POF especially on fused taper twisted in which POFs in bundle arrangement were all fused, twisted and merged. The change of original diameter of POF led to the change on optical properties including numerical aperture and critical angle of incident light. All of these changes spoil to light propagation principle based on total reflection.

The efficiency of POF coupler has been characterized right after the fused POF bundle cut at middle part where the diameters of POF bundle reaching 1 mm. The comparison for all power efficiency of optical 1x4 coupler based on POFs has been observed. As expected, the minimum output power will be obtained for each output ports is 3μW (as the optical power divided into four). From the observation of power efficiency measurement, the final result is obtained (see figure 11).

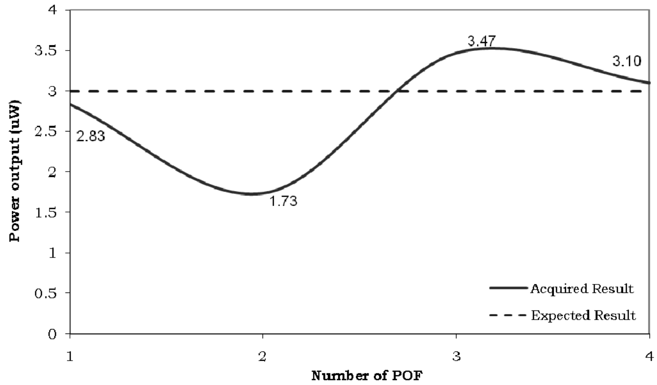

Figure 11 The analysis of output power measured at four POF ports of coupler's

The result above shows that there is optical power deviation between the obtained and expected result. However, the polygon line of obtained result is nearly approaching the linear line of expected result. Among the POF outputs, the second one exhibits the occurrence of great deviation between the obtained and expected result. The power efficiency of each output exhibits a different value with a maximum power efficiency reaching over 70%. Besides, the optical loss for the cascaded 1x4 coupler is amazingly less than 30 %.

At this point we would now like to define the term "connector attenuation". Strictly speaking, a connector does not have any defined losses, only a fiber-to fiber connection has losses. The light losses are caused by: inexact alignment of the fibers to each other, whereby the parameters of the fiber, the connector and the coupling could be responsible, the fiber parameters not being adapted to each other, e.g. different numerical apertures, and direct losses at the fiber end face through reflection, scattering and absorption [5].

Many factors can affect the efficiency level of coupler, other than imperfect shape, fabrication failure, and improper of jointing process , the presence of surrounding light, could be one of the factor cause an error on optical power meter, although have a low intensity they gave a high sensitivity on it. Optical power meter able to reach nanowatt external power, hence, disruption from external source of light ensured to be avoided during the power measurement conducted.

IV. CONCLUSION

To conclude, the modified fusion technique has been practiced successfully to fabricate the cascaded 1x4 POF coupler. Multimode SI-POF type with 1 mm core size fully utilized for the base material of the splitter. In order to implement fabrication technique, many aspects have been considered including health safety and the availability of apparatus. Some procedures, such as fabrication and characterization stages have been carried out to develop the coupler. Red LED with a 650 nm wavelength has been injected into the coupler for the purpose of characterization testing to analyze the level of power efficiency of the splitter. Final analysis shows that efficiency of the cascaded 1x4 POF coupler able to reach up to 70% with optical loss less than 30%. Thus, the obtained result reveals that low-cost cascaded 1x4 coupler has great potential to be applied as an economical wavelength division multiplexer because it could couple several different wavelengths with high power efficiency and low optical loss. The conventional POF coupler may be replaced with this novel coupler as economical wavelength division multiplexer. Thus, using this device as new multiplexer may cut overall cost of WDM-POF system and this will lead to the growth of WDM-POF system for in-home and car network as WDM solves problem regarding data capacity or transmission bandwidth.

The device performance can be more improved gradually time by time through experience and practice. Main point here is the fabrication process is simple, easy and suitable to be used for household. The fabrication method, however, afflicted with some disadvantage that no consistency of device production. Since the fusion technique implemented by handwork, the fabrication technique could not produce many couplers consistently due to the nature of human error. Further study on interfacing POF-based system for WDM application are advised to be conducted, all the way to improve the efficiency of POFs power transmission. In summary, the fusion technique has been successfully practiced to fabricate the handwork-fused 1x3 splitter based on POF technology. This handmade splitter can be applied in small-world communication system including in-home and car network. In future, it predicted to be alternative coupler in wavelengths multiplexing due to its major advantages, low-cost and high efficiency.

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