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Cost effective optical coupling for polymer optical fiber communication

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ABSTRACT

Polymer Optical Fiber (POF) optical modules are gaining momentum due to their applications in short distance communications. POFs offer more flexibility for plug and play applications and provide cost advantages. They also offer significant weight advantage in automotive and avionic networks. One of the most interesting field of application is home networking. Low cost optical components are required, since cost is a major concern in local and home networks. In this publication, a fast and easy to install, low cost solution for efficient light coupling in and out of Step Index- POF is explored. The efficient coupling of light from a large core POF to a small area detector is the major challenge faced. We simulated direct coupling, lens coupling and bend losses for step index POF using ZEMAX^R optical simulation software. Simulations show that a lensed fiber tip particularly at the receiver side improves the coupling efficiency. The design is optimized for 85% coupling efficiency and explored the low cost fabrication method to implement it in the system level. The two methods followed for lens fabrication is described here in detail. The fabricated fiber lenses are characterized using a beam analyzer. The fabrication process was reiterated to optimize the lens performance. It is observed that, the fabricated lenses converge the POF output spot size by one fourth, there by enabling a higher coupling efficiency. This low cost method proves to be highly efficient and effective optical coupling scheme in POF communications.

Key words: Polymer Optical Fiber, Lensed fiber, Optical coupling, Simulation, Detector, Fabrication, Characterization

1. INTRODUCTION

POFs are large core multimode optical fibers with very high numerical apertures. They have every advantage of optical fibers while maintaining the flexibility of copper cables in installation. POFs find exciting applications as low cost alternative in home networks, automotives and short reach applications¹. The lower connection costs and other low cost factors made large core multimode POFs attractive over single mode fibers for short distance communications. The major challenges for POF networks are low cost components, their packaging and the interfacing with existing networks. At present, both Light emitting diodes (LEDs) and vertical cavity surface emitting lasers (VCSEL) are being used as the light source. They give the cost advantage over laser diode as the light source. Since POFs are large core diameter fibers, the optical coupling is not an issue at the transmitter side. But the large core diameters always results in severe power coupling losses at the receiver side. The coupling losses lead to the reduction in maximum link distance achievable. Realization of additional coupling elements brings in process complexities at an added cost. This necessitates

At this juncture, the coupling can be improved by two ways: – either by an external discrete lens placed between the fiber and source/detector or by reshaping the flat fiber tip to a lens. A comprehensive analysis to improve the coupling efficiency with a discrete lens system and lensed fiber system yielded the results below.

The optical coupling simulations of POF with an external spherical ball lens are tried initially. Since the diameter of the POF is large, a large ball lens is required for better light coupling to the detector. But as the size of the coupling lens increases, the package dimension also becomes bigger. Various dimensions of ball lenses are simulated and a trade off between the package size and coupling efficiencies are reached. Based on these studies an optimum value of 2mm radius lens is simulated and it yielded a power output coupling efficiency of 37.45%. This shows that a discrete large ball lens would give better coupling efficiency in comparison to the bare fiber. However this coupling system will increase the dimensions of the transceiver module as the ball lens radius is large compared to the dimensions of the fiber, which is undesirable.

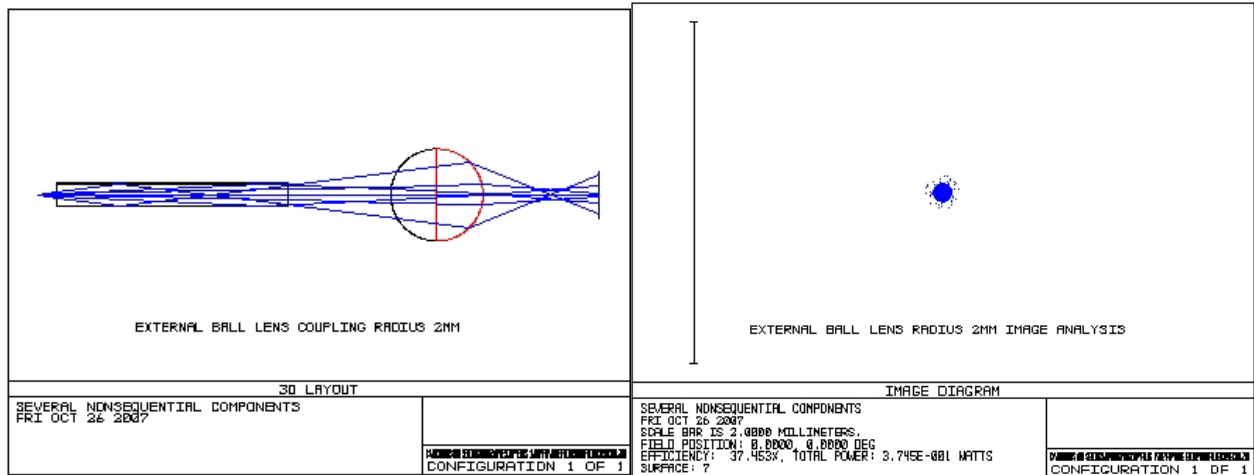


Fig 2. POF coupling using an external ball lens of radius 2mm

On the other hand, a discrete ball lens of radius 0.48mm is a better fit since it will not increase the optical sub assembly size required to hold the fiber-lens system. Conversely a small radius lens will focus the beam to a nearer point at the expense of power output while a large radius lens will focus at a longer distance from the lens and maintain the power output to a high value. This can be observed with the fall in power to 18.81% in comparison to the larger lens radius coupling efficiency of 37.45%. Moreover an aspherical lens can be used instead of a large ball lens to improve coupling efficiency. Then it becomes necessary to concentrate more on the alignment and orientation of the lens in the module that brings in additional cost and effort for the sake of increasing the power output.

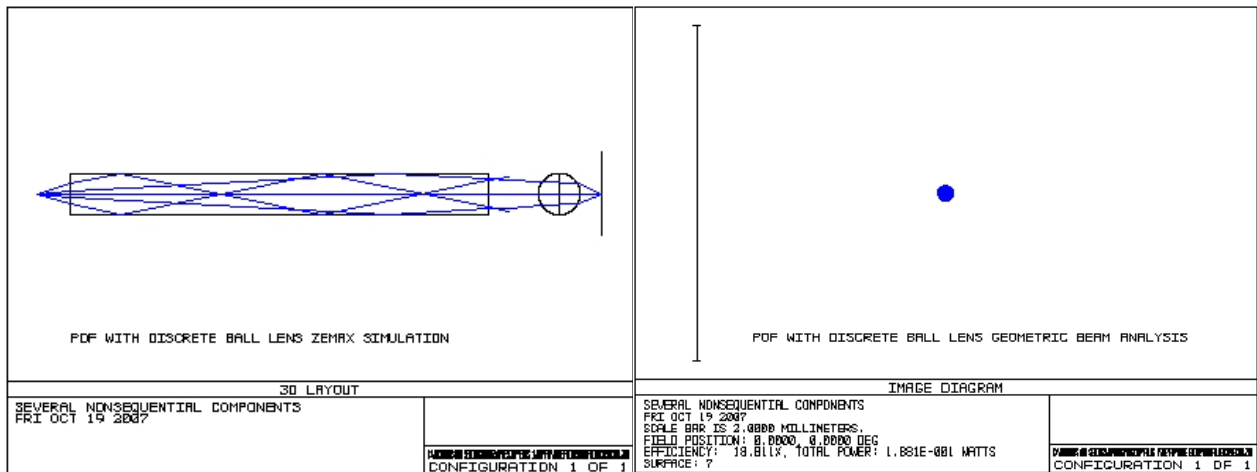


Fig 3. POF coupling using an external ball lens of radius 0.48mm

The following analysis discusses the proposed coupling type namely the hemispherical structure integrated to either side of the fiber. Here a plastic fiber of 0.49mm radius is simulated with hemispherical coupling ball lenses attached to both end of the fiber. The refractive indices of the fiber core and the hemispheres are made identical. Optimization of the simulation was carried out to find the optimal distance between the lenses and the fiber ends which would maximize the power output. The beam focusing distance from the lens at the receiver side is found to be 0.7mm. Also, a dummy surface with a circular aperture of 50 μ m radius is inserted just before the image surface. This is carried out in order to simulate the power incident on the surface of the photo detector of radius 50 μ m.

The simulation result shows an increased power coupling efficiency of 85%. The power is concentrated in the 20 μ m radius and hence shifting of the fiber by 15 μ m offset from the centre will not affect the coupling efficiency of the system. Since the POF diameter being inherently large, the hemisphere's radius is also large, thereby improving the spatial resolution of the image. Besides this, the whole system is spherically symmetric. This eliminates the need for orientation unlike in the case of an aspherical lens.

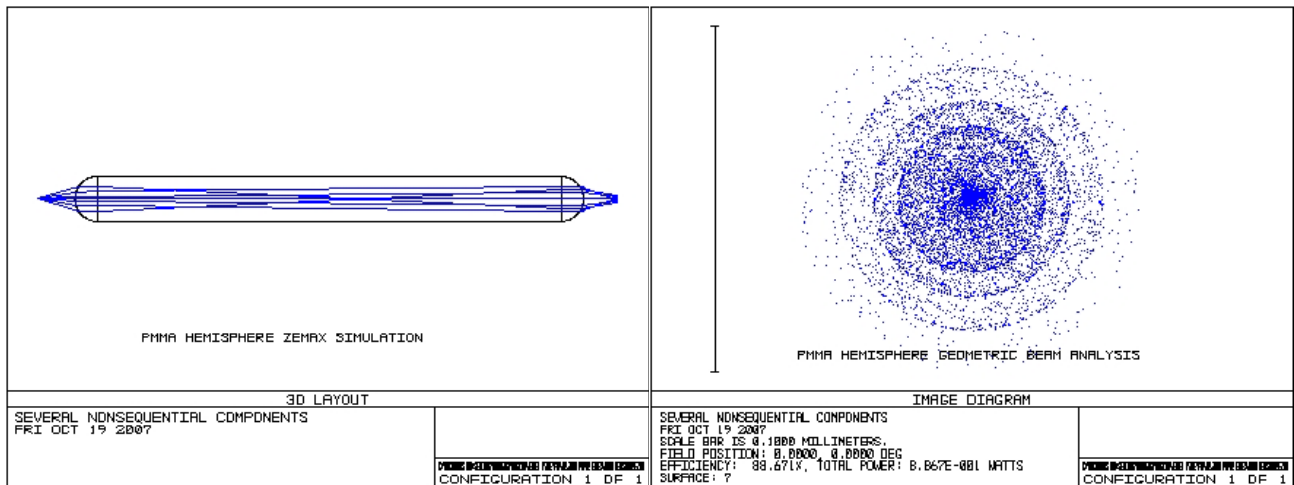


Fig 4. POF coupling using hemispherical lenses formed at the tip

The detailed analysis of various coupling schemes reveals that to improve the coupling efficiency with a discrete lens, the lens size has to be considerably bigger. But this greater coupling efficiency comes at the cost of a bigger transceiver package dimension and assembly costs. To maintain the package dimensions to minimum, lens size has to be the same as that of fiber where in the coupling efficiency drops significantly. On the other hand with a hemispherical lensed fiber tip both the higher coupling efficiency and compact package size can be achieved.

4. FABRICATION

The two simple techniques followed for the fabrication of lensed tip POF are:-

- (a) Lens formation at the fiber end face by pressing the end face against a hot lens forming mold²
- (b) Lens formation by dipping the polished fiber tip in an optically transparent organic liquid³

The process of fabrication of a lens by hot melting method onto a fiber of plastic or glass origins would include the mechanical process of injection molding or compression. The physical property of either a PMMA or perfluorinated polymer fiber and their lower fabrication temperatures have made the fabrication of lenses onto the fiber much easier.

Hot plate method requires the melting the fiber tip at its material melting point temperature and molding it with a suitable cavity to form the lens. Based on the simulation results we fabricated a die in steel material by precisely machining the requisite lens radius of curvatures. Apart from this the set up requires a hot plate to heat the mold and an arrangement to hold the POF vertically to the cavity. This simple fabrication setup and highly repeatable process makes the fabrication method cheap and attractive.

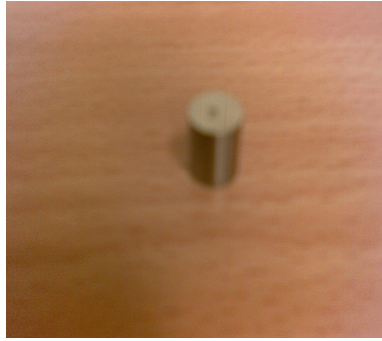


Fig.5. Steel cylinder with mechanical mold

The steel mold is heated to the required temperature initially. The temperature from the top of the mold is cross checked with the help of a thermo-couple to reaffirm the required temperature level. Once the temperature reaches an approximate level of 150C~160C, the fiber is lowered towards the mold and allowed to take the shape of the mold. The fiber is subsequently allowed to cool to normal room temperature for 3 - 4 minutes. The processed fiber under microscopic view shows the formation of a clear lens at the tip.



Fig. 6. Lens tip POF with Unpolished edges

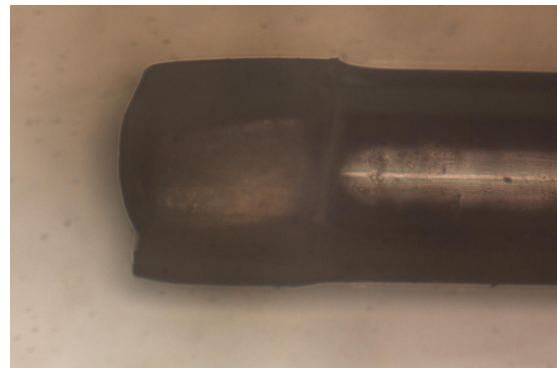


Fig.7. Lens tip POF with polished edges

During the fabrication, it is observed that the entire fiber area is touching the cylindrical mold surface. This leads to the melting of POF edges and creates unwanted curvatures, thereby reducing the effect of the lens. These extended portions are further polished down to give the perfect shape. A new mold with wider aperture is being considered to get rid of these problems. Another concern is that, if the molded portions are not allowed to cool down properly, instead of a perfect smooth spherical surface, a lot of fiber 'hairs' are being formed. This reduces the lensing effect and further polishing is required to make the surface perfect.

The polymer dip method involves the formation of a spherical convex contour at the end face of POF by immersing the tip in an organic solvent containing an optically transparent material. Here the fiber tip is polished initially by mechanical polishing. Once the polishing is done, the fiber ends are cleaned and dipped in to the polymer liquid. Then the fiber is pulled out and the liquid is allowed to take a convex lens shape under surface tension. The shape of the lens formed depends on the viscosity of the polymer and the time given to settle down. Once the required shape is reached the fiber tip is irradiated with UV light to make a proper adhesion. Many experiments have been carried out to optimize the required profile by using various viscous liquids and variable time for settling. The lens formed is as shown in the figure 9.

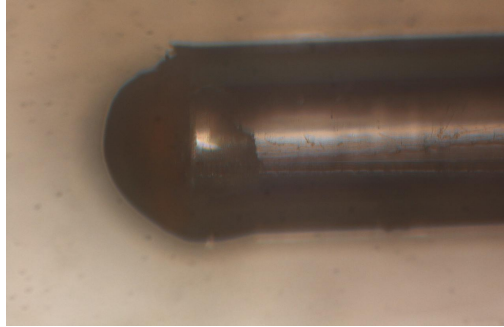


Fig.8. Hemispherical lens formed by polymer dipping

The characterizations of these lenses are being carried out to assess the lensing effect and their impact on coupling efficiency. Initial trials show a significant spot size reduction using these lensed fiber tips. Fabrication trials are in progress to optimize the lens performance.

5. CONCLUSION

We have analyzed the various possible optical coupling schemes by simulations for POF communication. It is realized that POF with a lensed tip is a cost effective coupling method for coupling light from the transmitter to the POF and from the POF to the photodiode. We have adopted low cost fabrication methods for realizing the lensed POF. In this coupling method, the hemispherical lens fabricated to the fiber tip makes the system simple and efficient. This eliminates precision subassembly and alignment, hence lowers the manufacturing cost. In addition to this, it is seen that reflections and scattering is greatly reduced at transition surfaces in the hemispherical model since the ball lens and the fiber are of precisely the same material. Since POF has large core radius, this hemispherical addendum will also have greater dimensions which will help to collect and focus light effectively and with ease of manufacturability. The device will be more mechanically stable, less prone to shock and vibrations as external components are minimized, thereby saving cost.

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REFERENCES

- 1). S. Junger, W. Tschekalinskij, N. Weber, Multimedia and multiservice systems for home, office and industrial networks, Asia-Pacific Optical and Wireless Communications Conference 2003, Wuhan, China, 4.11.2003
- 2). Y.Ohtsuka and Y.Hatanaka, "Preparation of light focusing plastic fiber by heat drawing process, Appl.Phys.Lett" vol 29, no. 11,pp 735-737, Dec. 1976
- 3). K. L. Mittal, Kang-wook Lee, "Polymer Surfaces and Interfaces: Characterization, Modification and Application" VSP, Science ISBN: 90-6764-217-7, July 1997
- 4). Yu-Kuan Lu, Ying-Chien Tsai, Yu-Da Liu, Szu-Ming Yeh, Chi-Chung Lin, and Wood-Hi Cheng "Asymmetric elliptic-cone-shaped microlens for efficient coupling to high-power laser diodes" Optics Express, Vol. 15, Issue 4, pp. 1434-1442
- 5). Fujimoto, N.; Rokugawa, H.; Watanabe, H.; Ishizuka, A.; Sukegawa, T, "Photonic access connector: a compact, gigabit optical link for plastic optical fiber" ECOC 15-19 Sept. 1996, Volume 2, Page(s): 59 - 62