Characterization of Fused Coluplers for Multimode Optical Fiber Systems

Terumi NOBUYOSHI

Department of Electronic Science,
Okayama University of Science, Ridai-cho 1-1 Okayama 700, Japan

Differential mode attenuation measurements according to the theory of Daido et al. have been performed on CVD-fabricated GI-fibers and biconically fused couplers made from these fibers. It is shown that the theory works well also with CVD fibers containing an index dip. It is demonstrated that coupling factors and loss figures are not sufficient to characterize fiber couplers. The mode-dependent coupler + fiber behaviour can be predicted as proved by measurements. Mode-insensitive couplers are not always optimal for systems.

1. Introduction

At present optical fiber coulers are specified like their hollow waveguide ancestors: coupling factor and insertion loss are the only informations provided. Comparing loss figures achieved in different laboratories, e. g. for the biconically fused coupler [1], one is struck by the quite different results. Rarely any information on measurement details is given. Regarding the coupling factor one would be at last surprised by implementing such a coupler in a system. With some fused SI-fiber couplers one can easily reach a variation of the power ratio between the output ports from e. g. 6 to 16 dB depending on launch conditions and applied cladding mode strippers.

The key to these phenomena is mode-dependent coupling. The answer seems to be a mode-insensitive coupler. Therefore, in many publication, e. g. [1], [2], more or less doughnut-shaped far-field patterns are depicted for SI-fiber couplers in order to give an impression of the modal dependence. To our knowledge the first really mode-controlled coupler fabrication has been described in [3] where also the achievement of a nearly mode-independent fused SI-fiber copler has been reported. Mode control has been performed by variation of the angle of incidence

of the input beam with a rotating glass cube and by simultaneous X-Y oscilloscope display.

This principle is not applicable to GI-fibers since a lot of different mode groups would be excited by this excitation. At present GI-fiber couplers are assessed mainly by the general outlook of their far-field or near-field(NF) pattern. As we will show this may lead to quite erroneous results.

2. Differential mode attenuation measurements on CVD fabricated fibers

Only recently, Daido and co-workers have published the first practical useful method to measure differential mode attenuation in GI-fibers [4]. So far measurements have only been reported on GI-fibers with a fairly smooth parabolic profile. It is questionable if this theory works also well on low loss CVD fabricated fibers with a large index dip at the center and some profile ripple.

Therefore, we measured a CVD-fiber fabricated in our lab according to their theory. Fiber data are : core dia. 53 μm, cladding dia. 98 μm, N. A. $\simeq$ 0.2, pure Ge-doped silica with boron ring. The fiber of 1 km length has been excited by light from a halogen lamp, filtered to 820 $\pm$ 6 nm, through a $\times$ 20 microscope objective. The fiber end face was projected to the vidicon surface of a measuring TV-system by a $\times$ 60 microscope objective. The recorded NF-pattern is shown in Fig. 1a together with the NFP obtained after cutting the fiber back to 2 mtrs. Since no special care about uniform illumination was taken, the NFP represents only roughly the index profile. Obviously a large index dip and profile ripples are
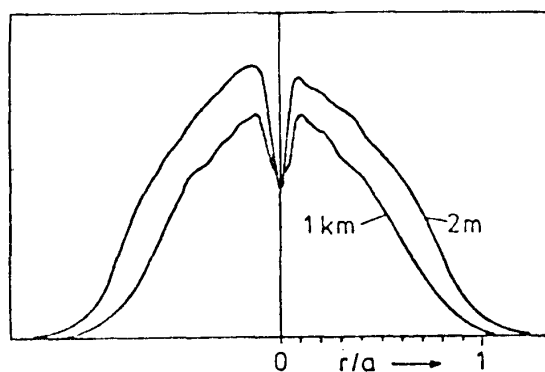
Fig. 1a. Near-field intensity pattern of
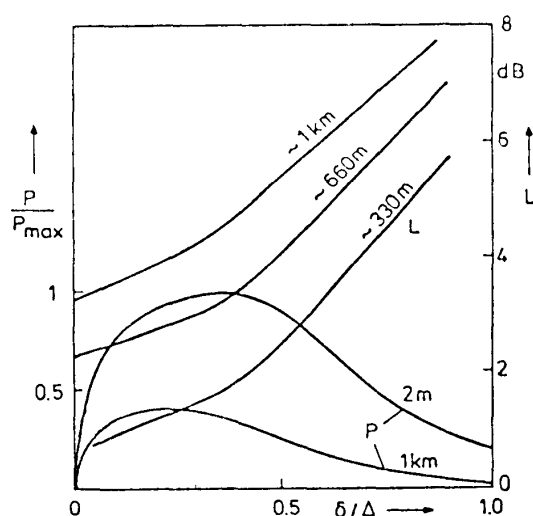GI-fiber at 2m and about 1 km.

Fig. 1b   Mode-power distribution and
differential mode attenution as
a function of normalized mode
number.

present. According to [4] the differential mode power $P(\delta/\varDelta)$ was calculated for $\delta/\varDelta = (r/a)^2$, assuming an $\alpha = 2$ profile. The resulting curves are shown in Fig. 1b. The ratio of the two curves yields the differential mode loss $L(\delta/\varDelta)$ for the 1 km fiber. By cutting back the fiber the losses for 330 m and 660 m pieces are determined the same way. Note that the index dip in Fig. 1a extending to $r/a = 0.1$ influences the curves of Fig. 1b only up to $\delta/\varDelta = 0.01$ and is no longer significant.

3. Measurement of mode dependent coupler behaviour

Curves as shown in Fig. 1 or in [4] look quite nice but there is still no proof of their practical relevance. It has to be demonstrated that any odd modal input excitaion will yield the same $P(\delta/\varDelta)$-curve for a given length of fiber when measured with the above procedure or when just measured near the input and then calculated with the help of $L(\delta/\varDelta)$ curves determined previously for that fiber.

Biconically fused couplers are known to show mode dependent behaviour. Therefore, we made a coupler near the input end of our fiber and recorded the NFP as described above for the coupled port (followed by 1 km of fiber without splices) and for the through port (~ 3 m fiber). Then the fiber was cut back to ~ 3 m from the coupled port and the NFP recorded again. Finally, the fiber was cut in front of the coupler and the input pattern was recorded. All NFP's are depicted in Fig. 2a. Obviously the shapes of the different curves do not look very much different. From these curves the varous $P(\delta/\varDelta)$ curves have been calculated (Fig. 2b). Then to the coupled port curve of Fig. 2b the differential mode loss
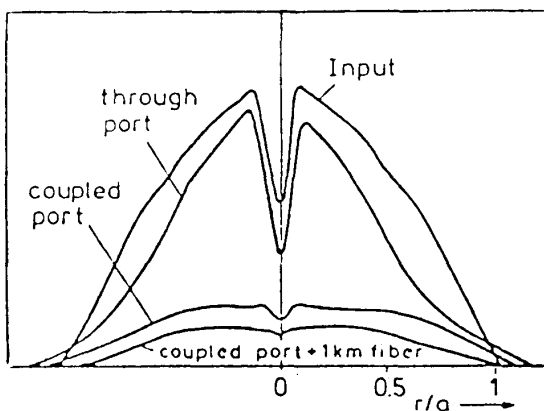

Fig. 2a. Near-field intensity patterns at various ports of coupler No. 2 and after 1 km at the coupled port.
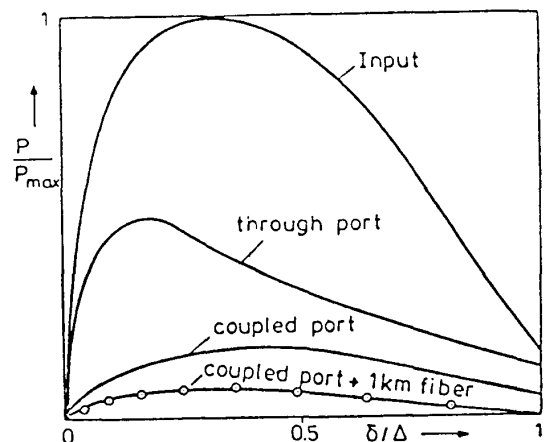
Fig. 2b. Mode-power distribution derived from measured NF patterns of Fig. 2a. Circles indicate the power distribution after 1 km behind the coupled port calculated from fiber differential mode attenuation.

$L(\delta/\varDelta)$ as depicted in Fig. 1b for 1 km of fiber has been added. The reult is shown in Fig. 2b by the small circles which quite closely follow the measured curve. This measurement has been repeated for different couplers with similar results. Therefore, this proofs that the theory of [4] will yield valuable results in predicting the influence of branching elements on GI-fiber systems behaviour, if modal patterns are not too strange.

To study the modal dependence of coupler performance three different couplers have been prepared from the same fiber. (It should be added that these couplers were the tedious procedure extracting all necessary information from a NF monitor pattern. Therefore, neither low loss nor optimized behaviour can be expected.) For these couplers the mode dependent coupling factor and the mode dependent insertion loss have been calculated with respect to the input port from curves Fig. 2b. Both curves for the three couplers are shown in Fig. 3a. The corresponding integral attenuations as measured with a detector are for the given excitation : coupling port 8.7 dB/7.5 dB/8.2 dB and through port 3.3 dB/3.7 dB/5.8 dB for the couplers 1/2/3, respectively.

It is seen that integral fiures do not give satisfactory description. Coupler 3
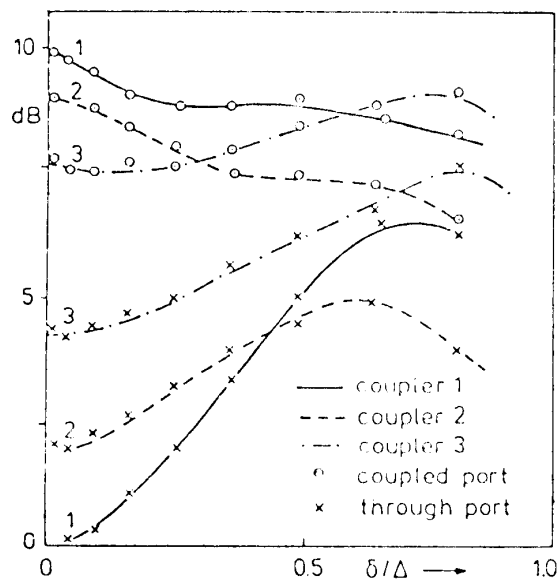

Fig. 3a. Mode dependent coupling and mode dependent insertion loss for 3 different couplers.
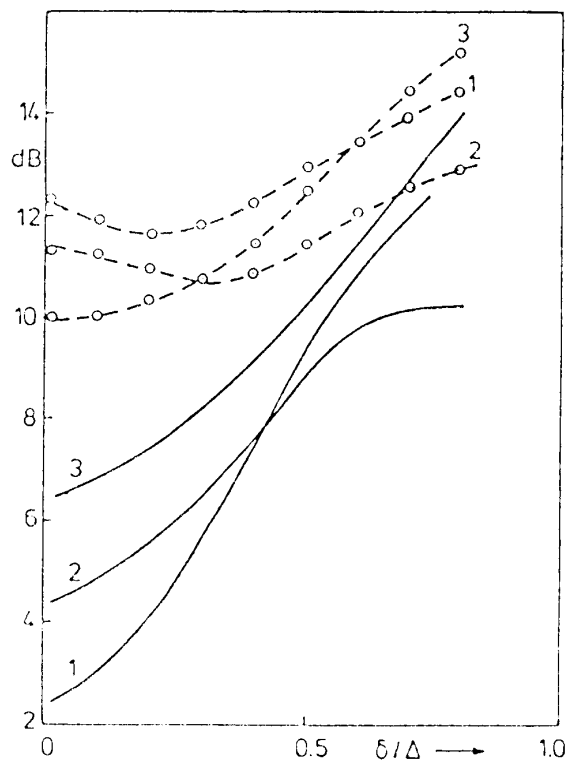

Fig. 3b. Cumulative mode dependent coupling and cumulative mode dependent insertion loss with 660 m fiber length for 3 different couplers.

shows comparatively low modal dependence but high loss. Coupler 2 is more typical in its high-order mode preference and its through port loss matches quite closely the fiber differential mode loss curve (1 km) in Fig. 1b within the most important region up to $\delta/\varDelta=0.64$ (r/a=0.8). The main modal dependence and excess loss seems always to occur in the through arm. Fig. 3a gives much insight in the coupler behaviour, but for the system designer the cumulative coupler + fiber loss is essential. This is depicted in Fig. 3b. One sees that the mode sensitive coupler 2 shows a cumulative compensating effect at its coupling port and is superior to a mode insensitve coupler in this respect. Further work has to show if this effect is possible for both ports. In conclusion, it is demonstrated that at least the curves of Fig. 3a and the fiber L-curves of Fig. 1b are necessary to assess the behaviour of a GI-coupler in a system environment. Therefore, with a given excitation the integral loss up to certain fiber lengths can be calculated. Complete calculation of the entire system configuration seems to be possible if modal curves are available for all passive parts.

Acknowledgment

References

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4) Daido, Y. et al.; Appl. Opt. 18, pp. 2207-2213 (1979)