Exact Splice Loss Prediction for Single-Mode Fiber

YUICHI USUI, TOSHIO OHSHIMA, YUICHI TODA, YASUYUKI KATO, AND MITSUHIRO TATEDA

Abstract—This paper describes the direct measurement method of spot size for single-mode fibers and its application to the splice loss prediction. Using a core-centering-type automatic fusion splicing machine, predicted splice loss is examined for several MCVD and VAD fibers. The accuracy of splice loss predicted by this method is better than that calculated from core radius and refractive index. The experimental splice loss is equal to the sum of the loss predicted by this method and the loss caused by the splicing technique.

I. Introduction

SINGLE-MODE fiber designed in a long wavelength region is the optimum transmission medium because of its low attenuation and large transmission capacity. Although it has many advantages, splicing of single-mode fiber is one of the most difficult problems for the single-mode transmission system. To realize a low-loss splice, we developed a core-centering-type automatic fusion splicing machine [1]. This machine can avoid the effect of core eccentricity and fiber diameter mismatch by its core-centering performance. The mean splice loss for identical single-mode fibers is 0.07 dB and its standard deviation is very small. Then, if the splice loss caused by the core diameter mismatch and the relative refractive index difference mismatch is obtained exactly, we can predict the loss margin for single-mode fiber transmission systems exactly.

The theoretical analysis of splice loss for step-index single-mode fiber is studied by Marcuse [2]. In splicing by the core-centering-type automatic fusion splicing machine, the misalignment is neglected and we get transmission coefficient T in

$$T = \left(\frac{2w_1 w_2}{w_1^2 + w_2^2}\right)^2 \tag{1}$$

where w is the spot size.

We can calculate the value of spot size w from core radius and relative refractive index difference. Because of the measuring accuracy limit of core radius a and relative refractive index difference Δ, it is difficult to calculate the exact value of splice loss from (1).

The measuring accuracy depends upon the deviation from step-index profile of actual fiber such as dip and the fractuations of refractive index along the radial direction. We can, however, anticipate that the direct measurement of spot size w gives the exact theoretical value of splice loss of single-mode fibers.

Manuscript received September 8, 1981; revised October 9, 1981.

Y. Usui, T. Ohshima, and Y. Toda are with Sumitomo Electric Industries, Ltd., Yokohama, Japan.

Y. Kato and M. Tateda are with the Ibaraki Electrical Communications Laboratory, Nippon Telgraph and Telephone Public Corporation, Tokai, Ibaraki, Japan.

II. Experiment

Beam spot size is measured by using the near field pattern (NFP) method. In this measurement, an Infra-Red Vidicon Camera is used as a detector and a light emitting diode ($\lambda_0 \sim 1.30\ \mu m$) is used as a light source.

The beam spot size is defined as the half-width of $1/e^2$ of the maximum power of NFP. The γ characteristics of the camera tube are corrected by a minicomputer after measuring the NFP data. Fig. 1 shows the NFP of a single-mode fiber.

To compare the correctness of the predicted splice loss between the calculated value from core radius a, and the relative refractive index difference Δ, and from directly measured spot size w, several different single-mode fibers were spliced together. The splices were done by the core-centering-type automatic fusion splicing machine. In order to obtain low-loss splice, a fiber end inclination angle less than 1 degree is required. So we checked the inclination angle by monitoring the coupling loss before fusion, that is, if the coupling loss between identical fibers was more than 0.5 dB or if that between different fibers was more than 0.6 dB, the fibers were cut again [1]. Four VAD single-mode fibers and five CVD single-mode fibers were used.

1) VAD–VAD Splicing: Fibers A and B were selected as mother fibers (light source side). Experimental values versus theoretical values are shown in Fig. 2 and the spliced fiber numbers are also illustrated.

2) CVD–CVD Splicing: Fiber e was selected as a mother fiber, and experimental results are shown in Fig. 3.

3) VAD–CVD Splicing: Fibers A and D were selected as mother fibers, and experimental results are shown in Fig. 4.

III. Discussion

From Figs. 2–4, it is obvious that the expected splice loss calculated from directly measured spot size w is more correct than the calculated one from a and Δ. The relation between the experimental values and theoretical values are shown in empirical equation (2)

$$\alpha\text{exp} = \alpha\text{th} + \delta \tag{2}$$

where

αexp = experimental splice loss of single-mode fiber,
αth = theoretical splice loss of single-mode fiber,
δ = splice loss caused by splicing technique.

0018-9480/82/0400-0601$00.75

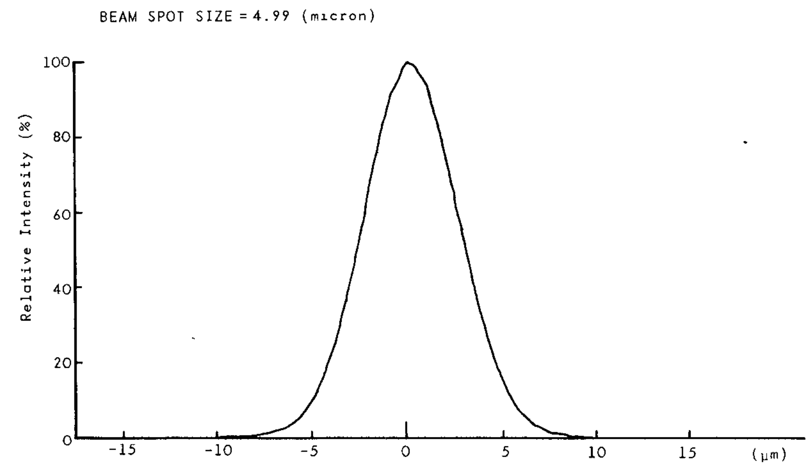


Fig. 1.

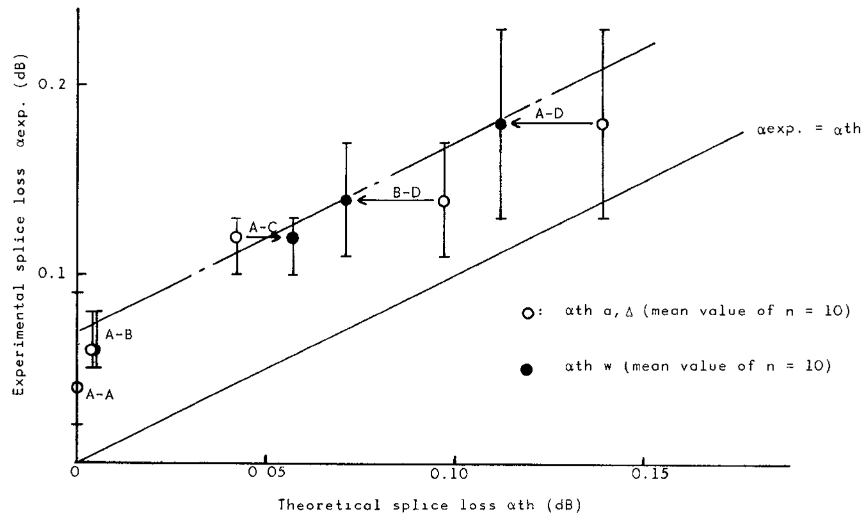


Fig. 2.

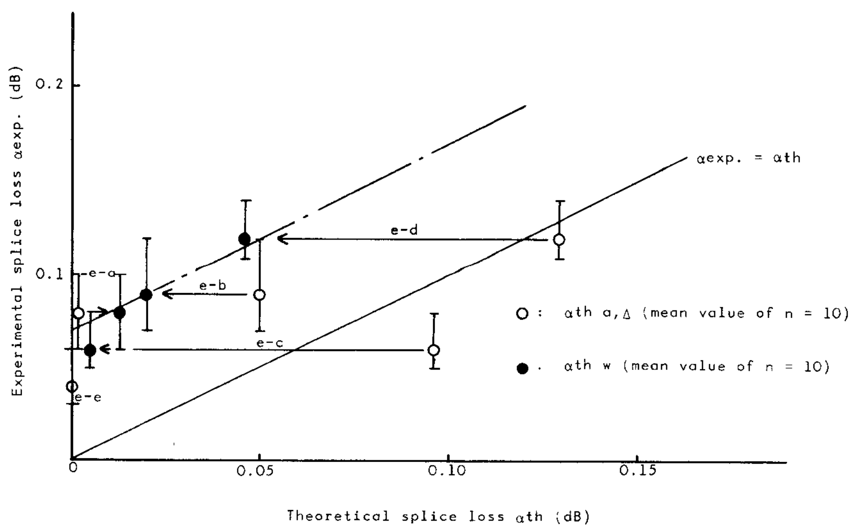


Fig. 3.

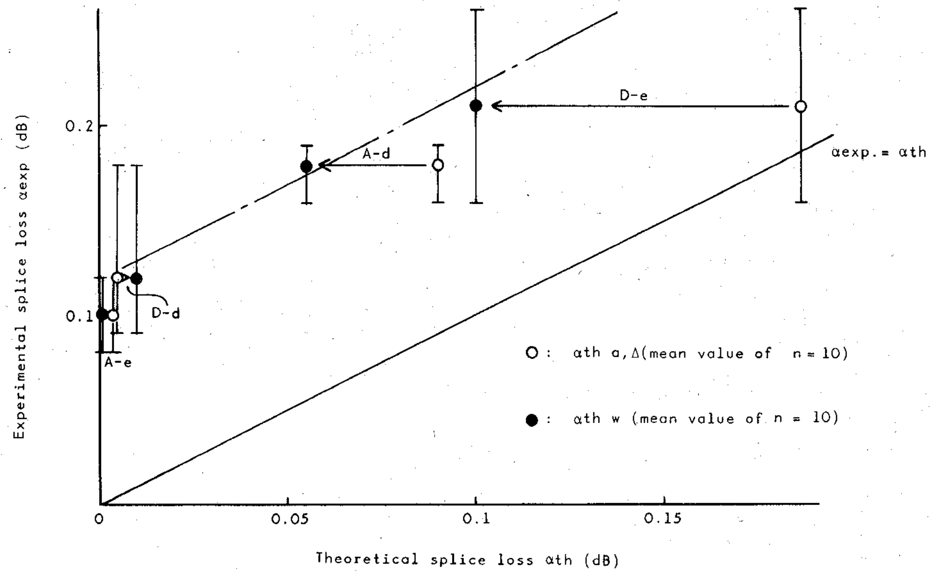


Fig. 4.

In the case of same manufacturing (processed fibers such as VAD-VAD or CVD-CVD), δ is 0.07 dB. But in the case of different manufacturing (processed fibers such as VAD-CVD), δ is 0.12 dB.

The difference of δ by the manufacturing process may be caused by the splicing condition itself. In case of different refractive index profile, the melting phenomenon may be changed.

IV. Conclusion

We developed the direct measuring method for spot size of single-mode fiber and obtained that the only way to obtain the exact value of the theoretical splice loss of single-mode fiber is to calculate from directly measured spot size w.

The experimental splice loss is found to be larger than the theoretically predicted value and deflection δ is 0.07 dB for the same manufacturing processed fibers and 0.12 dB for different manufacturing processed fibers. The difference of δ between the manufacturing process may be induced by the difference of melting conditions. Then, we can predict the splice loss of single-mode fiber exactly calculating from directly measured spot size w, which will contribute design to the single-mode fiber transmission system.

Acknowledgment

The authors would like to express their sincere appreciations to N. Uchida and S. Seikai for warm encouragement and valuable discussions.

References

[1] Y. Toda, O. Watanabe, M. Ogai, and S. Seikai, "Low-loss fusion splice of single mode fiber," presented at ICC '81, Denver, CO, 1981.

[2] D. Marcuse, "Loss analysis of single-mode fiber splices," *Bell Syst. Tech. J.*, vol. 56, no. 5, pp. 703–718, 1977.

Yuichi Usui was born in Nagano Prefecture, Japan, on February 2, 1950. He received the B.E. degree in mechanical engineering from Kyoto University, Kyoto, Japan, in 1973.

In 1973 he joined Sumitomo Electric Industries, Ltd., Yokohama, Japan. Since 1975 he has been working in the Communications Research & Development Department, Sumitomo Electric Industries, Ltd. He has been engaged in developmental research on optical fiber splice.

Mr. Usui is a member of the Institute of Electronics and Communication Engineers of Japan.

Toshio Ohshima was born in Kanagawa, Japan, on August 26, 1951. He received the B.S. and M.S. degrees in applied physics from Tokyo University, Tokyo, Japan, in 1974 and 1976, respectively. In 1979 he entered the Ph.D. course for physics at the University of Tsukuba, Ibaraki, Japan.

He joined Sumitomo Electric Industries, Ltd. in 1979, and was engaged in the study of transmission characteristics and the development of various measuring systems of optical fiber. He is currently engaged in research in the Fiber Optics Engineering Section.

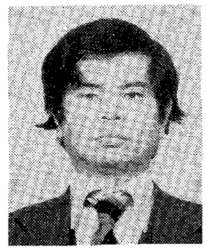
Yuichi Toda was born in Hyogo, Japan, on September 5, 1945. He received the B.E. degree in mechanical engineering and the M.E. degree in engineering from Osaka University, Osaka, Japan, in 1968 and 1970, respectively.

He joined Sumitomo Electric Industries, Ltd., where he was engaged in the development of communication cable manufacturing process and optical fiber jointing method. He is now Senior Engineer of the Communications Research & Development Department.

Mr. Toda is a member of the Japan Society of Mechanical Engineers as well as a member of the Institute of Electronics and Communication Engineers of Japan.

Yasuyuki Kato was born in Yamagata Prefecture, Japan, on July 20, 1954. He received the B.S. degree in electrical engineering from the University of Yamagata, Japan, in 1977.

In 1977 he joined the Ibaraki Electrical Communication Laboratory, Nippon Telegraph and Telephone Public Corporation, Tokai, Ibaraki, Japan. His current interests are in the transmission characteristics of low-order mode optical fiber cables and single-mode fiber splice.



Mitsuhiro Tateda was born in Kochi, Japan, on September 1, 1949. He received the B.S. and M.S. degrees in physical engineering from the University of Tokyo, Tokyo, Japan, in 1972 and 1974, respectively.

From 1974 to 1977 he was a member of Musashino Electrical Communication Laboratory, Nippon Telegraph and Telephone Public Corporation, Musashino, Tokyo, Japan. Since 1977 he has been an engineer at Ibaraki Electrical Communication Laboratory, Nippon Telegraph and Telephone Public Corporation, Tokai, Ibaraki, Japan. He has been working on the optical fiber transmission characteristics of optical fibers, multimode graded-index, and single-mode fibers for the practical design of trunc-line optical cables.

Mr. Tateda is a member of the Optical Society of America and the Institute of Electronics and Communication Engineers of Japan.

Two-Wave Sum-Frequency Light Generation in Optical Fibers

YASUJI OHMORI AND YUTAKA SASAKI

Abstract—**The generation of phase-matched two-wave sum-frequency light has been observed in optical fibers. A Nd:YAG laser by simultaneous mode-locking and Q-switching or only Q-switching operation is used as a pump laser. The input power dependence and fiber length dependence of the sum-frequency light are investigated in the two pumping methods. The observed coherence length for the sum-frequency light generation is about 200 m.**

I. Introduction

Low-loss optical fibers have proven to be highly suitable media for the observation of a wide variety of optical nonlinear effects, such as stimulated Raman scattering [1]-[4], stimulated Brillouin scattering [5], [6], self-phase modulation [7], and phase-matched four-photon mixing [8], [9]. The reason has to do with high optical intensities maintained over long lengths in small-core and low-loss fibers.

Low-loss optical fibers have come to be applied to active elements for generating new laser wavelengths [10]-[12] by using stimulated Raman scattering and phase-matched four-photon mixing processes. The generation of a near-infrared continuum covering the 0.7-2.1 μm range by use of a Q-switched Nd:YAG laser with 50 kW pump power coupled into multimode fibers has been observed previously [11]. In that work, transitory observations of visible-light generation were made. Recently, the wideband spectrum covering the 0.3-2.1 μm range was observed by using a mode-locked and Q-switched Nd:YAG laser with more than 100 kW pump power coupled into multimode fibers [13]. In this work, the generation of sum-frequencies was observed in cladding modes of silicone plastic coated fibers with 5-15 m lengths and a 50 μm core diameter.

In a previous letter [14], the authors reported the first observation of phase-matched two-wave sum-frequency light generation achieved by using waveguide modes of optical fibers. The mechanism of sum-frequency light generation, however, has not been readily explainable because the two-order dipole nonlinear coefficient for silica-based fibers has been thought to be zero. It is, therefore, very interesting to investigate how the sum-frequency light generation depends on pumping light, fiber length, or exciting condition.

This paper describes characteristics of sum-frequency light generation in optical fibers. The two-wave sum-frequency light waves were generated from the pump and the Stokes waves in optical fibers, pumped by a mode-locked and Q-switched Nd:YAG laser or a Q-switched Nd:YAG laser. The input power dependence and fiber length dependence of the output power of 0.54 μm light, which is generated from a combination of the pump light of 1.064 μm and the first Stokes light of 1.12 μm, were investigated in the two pumping methods. The sum-frequency light generation was also investigated in optical fibers in which the two modes (LP_{01} and LP_{11}) were excited. In this exciting condition, 0.53 μm light which is the second harmonics of 1.064 μm pump light, was newly observed.

Manuscript received September 4, 1981; revised December 9, 1981.

The authors are with the Ibaraki Electrical Communication Laboratory, Nippon Telegraph and Telephone Public Corporation, Tokai, Ibaraki-ken, Japan.

0018-9480/82/0400-0604$00.75