

# Arc discharge model design and splicing quality evaluation of a kind of PM fiber

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An arc discharge model of fiber splicing is proposed to improve the splicing quality of Polarization Maintaining (PM) fiber. The mathematic form of arc discharge function of fiber splicer and the movement control method of spliced fibers are proposed. A series of indexes, including the splicing loss, the extinction ratio, the maximum tensile strength, and the Weibull distribution based reliability index, are proposed to evaluate the splicing effect. The Support Vector Machine (SVM) is used to evaluate the integrated splicing quality of a kind of Interferometric Fiber Optic Gyroscope (IFOG). Many experiment results have shown the validity of proposed techniques.

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*Keywords:* Fiber splicing, Arc discharge function, Movement control, Splicing effect evaluation, Environment worthiness experiments

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## 1. Introduction

The fiber fusion operation [1] is a basic process procedure of the optoelectronic product manufacture [2], such as the design and assembly of temperature sensor or fiber optical gyroscope, etc. The familiar fiber fusion techniques include [3] the stickiness based method, the mechanical connection based method, and the fiber splicing based method. Because of the high reliability and facility, the fiber splicing based method [4] is used widely in practical engineering application. The fiber splicing based method uses the fiber splicer to connect the separated fibers. The fiber splicer is a machine which can connect two fibers together by the consecutive arc discharge [5]. Although the fiber splicer has many good characters, such as the high working stability and the excellent splicing effect; however, the design and the control of splicing process are really a complex task: both the materials character and the optical performance of spliced fibers, together with the arc discharge intensity, should be controlled elaborately. As a result, the current research topics about the fiber splicing process at least include: how to improve the final optical performance and the mechanical intensity of spliced fibers, and how to evaluate the splicing quality of them, etc.

Many research works have been done to realize and improve the fiber connection effect. In [6], two types of field installable connection techniques were developed. One was the mechanical splicing, and the other was the field assembly connection technique. The good optical performance and low average insertion loss could be gotten by those proposed methods. In [7], the Brillouin scattering spectrum of photonic crystal fiber was measured when the core-offset splicing case was implemented. The

strain and temperature influence factors were also considered when the splicing effect was analyzed. In [8], the fusion splicing method of a PM photonic crystal fiber and a conventional PM fiber was reported. The theoretical calculation of the splicing loss which was based on mode field diameters mismatch of two fibers was given. According to the practical application of complex optoelectronic product, the splicing technique actually belongs to a process research problem, which needs to consider not only the material character of fiber but the arc discharge function design of fiber splicer. In addition, the evaluation of splicing effect and quality should also consider many different practical application environments.

In this paper, a new arc discharge function design method and the splicing reliability evaluation techniques for the splicing case of a kind of Polarization Maintaining (PM) fiber are proposed. As for the arc discharge function design issue of PM fiber, a new mathematic form of piecewise function is proposed to implement the arc discharge control of fiber splicer. The movement control method of spliced fibers is also developed. As for the splicing quality evaluation problem, multiple indexes [9], including the splicing loss, the extinction ratio, the maximum tensile strength, and the splicing reliability, are all proposed to assess the splicing effect of PM fiber and the PM fiber related application system. The Support Vector Machine (SVM) classifier [10] is utilized to evaluate the integrated performance of splicing point for an Interferometric Fiber Optic Gyroscope (IFOG) [11]. Four splicing evaluation indexes are regarded as the training data of SVM; while the zero bias of IFOG is looked as the supervising data of SVM. A series of environment worthiness experiments [12], including the temperature test

experiment, the vibration experiment and the aging experiment, are all utilized to test the correctness and validity of proposed splicing technique.

The main contributions of this paper include: first, a new arc discharge function for the splicing issue of a kind of PM fiber is proposed. The movement control method of that arc discharge function is also developed. Second, a machine learning based splicing effect evaluation technique for both the individual spliced fiber and the assembled fibers is designed. With the application of proposed techniques above, the manufacture quality of optoelectronics product can be improved dramatically.

In the following sections, first the fiber splicing process technique will be reviewed. Second, the design of arc discharge model will be presented. Third, the evaluation method of splicing reliability will be introduced. Finally, some experiments and discussions will be given.

## 2. The fiber splicing process technique

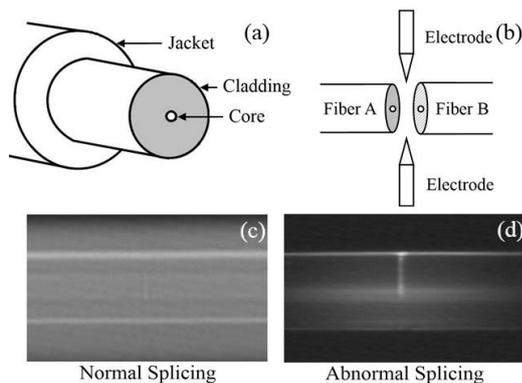


Fig. 1. The basic structure of fiber, the arc discharge generation principle of a kind of fiber splicer, and the image samples of spliced fiber

Fig. 1 shows the basic structure of a fiber and the arc discharge generation principle sketch map of a kind of fiber splicer. In Fig. 1 (a), the fiber includes three parts: the jacket, the cladding, and the core. Fig. 1 (b) shows the fact that the electrodes inside of fiber splicer can generate a powerful electrical arc to melt and splice the fiber materials. Because most of fibers work according to the law of total reflection, the splicing process is an important issue for the fiber related application. Fig. 1 (c) and (d) show the image cases of normal and abnormal splicing results. These images are captured by the cameras inside of fiber splicer directly. The abnormal splicing will appear for many reasons, such as the manufacture quality of fiber, the different arc discharge function design method, or the mismatch of fiber type, etc. When using the fiber splicer, the operation steps include: peeling off the jacket, cleaning the exposed cladding by the alcohol cotton, putting the fibers into the grooves of splicer, chucking and aligning the fibers tightly, and splicing two fibers by the consecutive arc discharge. During those processes above,

the splicing loss [13] can be estimated by the fiber splicer automatically.

Generally, the splicing process of fiber splicer at least include three steps: the step of core axis matching, the step of stress region matching, and the step of arc discharge splicing. Many research works have been done on the former two steps [14]; however, the reports about the design method of arc discharge function are rare. This phenomenon comes from the fact that the fiber has various kinds of types and commercial brands, their material characters and optical performance are different; in addition, different fiber splicer will employ different arc discharge design criteria and fusion processes to implement the fiber splicing task [15]. Although many fiber splicers provide a flexible setting method of arc discharge function; however, the design of the arc discharge model is still an experiment based research problem. For example, in [16], the authors discussed the arc calibration method for the fiber splicing issues with different diameters. Many splicing experiments were designed and implemented to assist the design of the arc calibration method. In this paper, some commercial Polarization Maintaining (PM) fibers are utilized in a splicing experiment, and a PM fiber splicer is employed to carry out the fiber splicing task.

## 3. The design of arc discharge model

Fig. 2 shows a traditional arc discharge model of a PM fiber splicer. Fig. 2 (a) is the basic model of arc discharge function and its movement control method; Fig. 2 (b) and (c) are a specific splicing method. These models are proposed by the fiber splicer provider. Before splicing, two fibers are put into the opposite sides of the arc discharge center; their separate distances between the fiber end face and the arc discharge center are equal. The arc discharge process [17] includes three steps: the pre-discharge, the first arc discharge, and the second arc discharge. The pre-discharge process begins from the starting point of arc discharge and ends when the fiber end faces butt each other together. In that situation the end faces of two fibers will be pushed to arrive at the center of arc discharge. The first arc discharge begins when the fibers arrive at the center of arc discharge and ends when the fibers are pulled back. During that process, the fiber end faces will be melted together and some deformations may occur. The second arc discharge begins when two fibers are pulled back and ends when it is necessary. During that process, the fibers will be pulled back till no obvious deformations exist in their surface at the very start; then the spliced fibers keep still, only the consecutive arc discharge will be executed. In Fig. 2 (b) and (c), during the second arc discharge, no arc discharge and movement control are released and carried out.

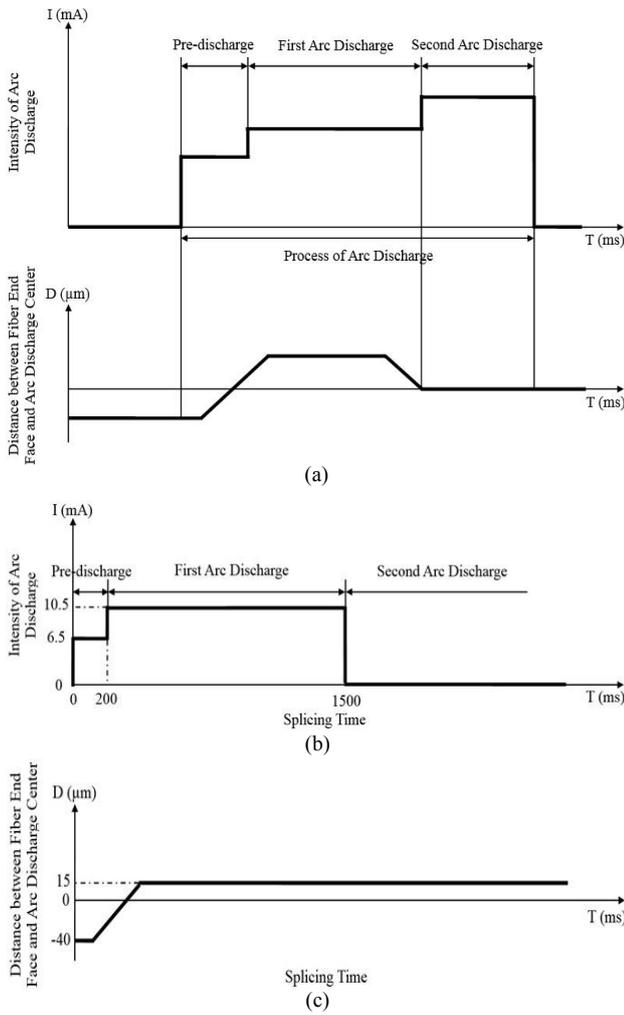


Fig. 2. The original arc discharge function and the movement control method of a kind of fiber splicer

An improved design of the arc discharge function and the fiber movement control method are proposed in this paper. Fig. 3 shows the design method of fiber splicing model. In Fig. 3, (a) is the intensity of the proposed arc discharge function, (b) is its fiber movement control method (i.e., the distance change state) of one of the fiber end faces. Equation (1) is the mathematical form of the proposed arc discharge intensity function; and equation (2) is the form of the distance change state of spliced fiber. The main arc discharge time, including the first arc discharge time and the second arc discharge time, can be verified by equation (3). From Fig. 3: after the push of fibers, no pull back operation is implemented, and only some arc discharges are executed on the surface of the spliced fibers. This design method comes from the fact that the fiber defects [18] always appear easily during the splicing process for this kind of PM fiber. If the fibers are pulled back, the fiber materials in the arc discharge center will be decreased; as a result the splicing defects may appear easily in that position. Here, the familiar splicing defects include: the bubbling defect, the neck-down defect, or the thickening defect, etc. After some experimental

evaluations, the proposed method can avoid those defects to some extent.

$$I = \begin{cases} 10.0 & 200.0 > T \geq 0.0 \\ 10.5 & 220.0 > T \geq 200.0 \\ 15.0 & 2500.0 > T \geq 2200.0 \\ 0.0 & T \geq 2500.0 \end{cases} \quad (1)$$

$$D = \begin{cases} -30.0 & 100.0 > T \geq 0.0 \\ kT & 300.0 > T \geq 100.0 \\ 20.0 & T \geq 300.0 \end{cases} \quad (2)$$

$$T_M = T_I + T_S \times m - T_E \quad (3)$$

where  $T$  represents the splicing time,  $I$  is the intensity of arc discharge,  $D$  is the distance between the fiber end face and the arc discharge center, and  $k$  is the factor of push speed.  $T_M$  is the main arc discharge time,  $T_I$  is the initial main arc discharge time,  $T_S$  is the single arc discharge time,  $m$  is a multiplier,  $T_E$  is an experiential correct factor. In this paper,  $T_I=2000.0\text{ms}$ ,  $T_S=100.0\text{ms}$ ,  $m=3$ ,  $T_E=200\text{ms}$

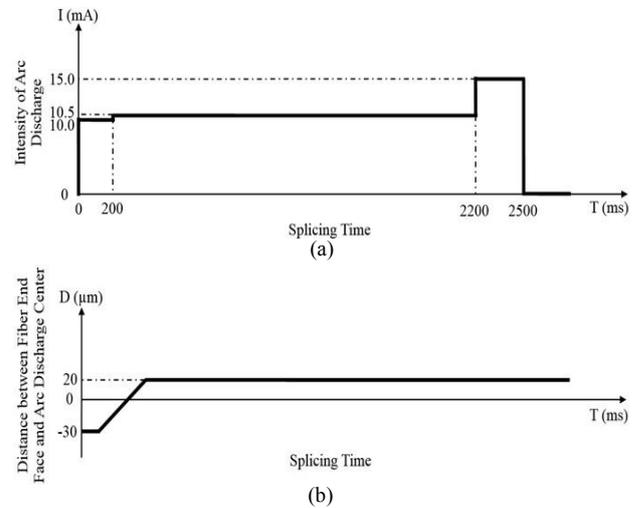


Fig. 3. The proposed arc discharge function and its movement control method for a kind of PM fiber

The movement control [19] of spliced fibers is a complex problem. Fig. 4 shows the sketch maps of fiber end face and its movement control methods. In Fig. 4, (a) shows three typical unqualified cutting end faces of the spliced fiber. The top one has a large cutting angle which may lead to a gap defect of the spliced fibers; the middle one has some impurities in the surface of fiber end faces which may lead to a drape defect; and the bottle one has a coarse end face which may cause the bubble defect. Images (b) and (c) show the improper movement control method of the spliced fibers. In (b) and (c) two fibers are

pushed just to touch each together slightly, as a result the gap defect and the bubble defect may occur in the junction of the spliced fibers. Image (d) shows the correct push method: because the extrusion operation is made in the fiber junction, the familiar defects like the gap defect or the bubble defect can be avoided if the proper electricity is released on the surface of spliced fibers.

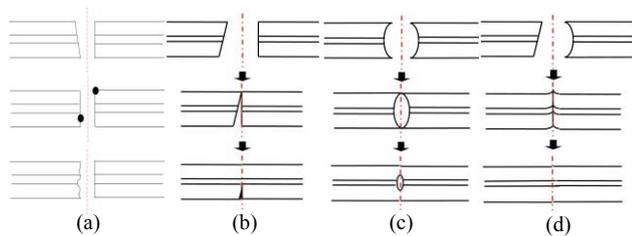


Fig. 4. The sketch maps of fiber end face and its movement control method

#### 4. The evaluation of splicing quality

Many indexes are utilized to evaluate the splicing effect of PM fiber, they include: the splicing loss, the extinction ratio, the maximum tensile strength of splicing point, and the splicing reliability. The splicing loss and the extinction ratio belong to the traditional evaluation indexes of fiber splicing; both of them can be estimated by the fiber splicer itself directly. However, the estimated results of them always are not as precise as we have expected in many practical applications because of some uncertainty factors, such as the random noise, the unsteady current, or even the error from the estimation model of splicing loss. To improve the reliability of splicing quality evaluation, the Optical Time Domain Reflectometer (OTDR) [20] can be employed to test the optical power. Thus, with the output of OTDR, the splicing loss and the extinction ratio can be calculated by equation (4) and equation (5), respectively. The average measurement error of OTDR can be controlled less than 0.02dB.

$$\alpha = -10 \times \log_{10} \frac{P_o}{P_i} \tag{4}$$

$$\beta = -10 \times \log_{10} \frac{P'_o}{P'_i} \tag{5}$$

where  $P_o$  is the input optical power while  $P_i$  is the output optical power of fiber respectively;  $P'_o$  is the optical power of optical source,  $P'_i$  is the optical power of output light in the orthogonal direction, respectively.

The maximum tensile strength is an important evaluation index which will reflect the fracture lifetime of the fiber related application system. As we know, the main materials of fiber are  $\text{SiO}_2$ ; thus the theoretical fracture intensity of fiber is decided by the bonding force of  $\text{SiO}_2$  molecule. The fracture intensity  $\sigma$  of a quartz optical fiber

can be estimated by equation (6). According to (6), the theoretical fracture intensity is  $1.587 \times 10^3 \text{kg/mm}^2$ . If the cross section area of fiber whose diameter is  $125\mu\text{m}$  is  $D_{125} = 1.227 \times 10^{-2} \text{mm}^2$ , the theoretical fracture strength of fiber can be  $F_{125} = \sigma \times D_{125} = 19.5 \text{kg}$ . As for the tensile strength index of splicing point, it can be measured by the fiber tensile tester. The fiber tensile tester will execute forces on the spliced fibers until the fracture phenomenon of spliced fibers happens. And the maximum fracture strength will be recorded as the maximum tensile strength of the splicing point. The mechanical control method of the fiber tensile tester can be designed by equation (7).

$$\sigma = \sqrt{E \cdot \gamma / A} \tag{6}$$

$$F = F_0 + ft \tag{7}$$

where  $E$  is the Young's modulus,  $E = 72000 \text{kg/mm}^2$ ,  $\gamma$  is the surface energy of  $\text{SiO}_2$ ,  $\gamma = 7 \times 10^{-5} \text{kg/mm}$ , and  $A$  is the length of chemical bond Si-O,  $A = 2 \times 10^{-7} \text{mm}$ ;  $F_0$  is the initial tense,  $f$  is the increase speed of tense, and  $t$  is time. In this paper,  $0.0\text{N} \leq F_0 \leq 4.0\text{N}$ ,  $1.0\text{N/s} \leq f \leq 10.0\text{N/s}$ ,  $1.0\text{s} \leq t \leq 2.0\text{s}$ .

The reliability of fiber splicing point can be described by the Weibull distribution [21]. As for the fiber related product, such as the IFOG, if the assembly splicing process of multiple splicing points can be regarded as a series system, the splicing reliability can be estimated for the entire electronic system. The mathematic form of Weibull distribution can be written by equation (8); the reliability index of Weibull distribution can be calculated by (9). And the reliability of a series splicing system can be assessed by (10). In (8), the parameter  $m$  is the scale index of Weibull distribution; it indicates the mechanical intensity of a fiber; while the parameter  $\eta$  means the stress item when the fiber fracture happens. The maximum likelihood estimation [22] can be used to assess those parameters of Weibull distribution. Once the parameters  $m$  and  $\eta$  are estimated for a typical fiber, the reliability index of both the fiber itself and its assembly product can be computed.

$$F(t) = 1 - \exp \left[ - \left( \frac{t}{\eta} \right)^m \right] \tag{8}$$

$$R_i(t) = \exp \left[ - \left( \frac{t_i}{\eta_i} \right)^{m_i} \right] \tag{9}$$

$$I_R = R_1(t)R_2(t) \dots R_n(t) \tag{10}$$

where  $t$  is time,  $m$  and  $\eta$  are parameters of Weibull distribution,  $t_i$  is the time point of the  $i^{\text{th}}$  splicing point,  $m_i$  and  $\eta_i$  are the parameters of the  $i^{\text{th}}$  splicing point,  $R_i(t)$  ( $i = 1, 2, \dots, n$ ) is the reliability index of the  $i^{\text{th}}$  splicing point,  $n$  is the number of splicing point, and  $I_R$  is the fiber splicing reliability index of the multiple fiber splicing point in a series system.

Finally, to evaluate the integrated splicing effect of multiple splicing points, the SVM classifier can be utilized to assess the splicing quality. As for an IFOG product,

many splicing points coexist inside of its body; in that situation the splicing quality of single splicing point cannot stand for the whole product quality of IFOG. That is to say the engineer cares for the integrated product quality evaluation rather than the assessment of a single splicing point. Thus the SVM classifier is used to evaluate the integrated splicing effect. The input data of SVM include the splicing loss, the extinction ratio, the maximum tensile strength of splicing point, and the Weibull distribution based splicing reliability; the supervising data of SVM is chosen by the zero bias of IFOG. The supervision training technique [10] is employed to train the SVM. And if a SVM is trained, it will have the ability to forecast the integrated splicing quality of a new IFOG product.

## 5. Experiments and discussions

Many practical experiments are implemented to test and verify the correctness and the effectiveness of proposed fiber splicing process techniques. A kind of PM fiber and the FSU975 fiber splicer machine are used to participate the splicing effect evaluation experiment. The basic optical performance parameters of PM fiber are shown in Table 1. All the computation programs are written by c and Matlab in our PC (2.4GHz CPU and 3GB RAM).

Table 1. The basic optical parameters of a kind of PM fiber

Jacket diameter (μm)	Cladding diameter (μm)	Core offset (μm)	Working wavelength (nm)
245.0±7.0	125.0±1.0	≤1.0	1550
Cutoff wavelength (nm)	Mode field diameter (μm)	Attenuation (dB/km)	Polarization crosstalk (dB)
1290-1520	6.5±1.0	≤0.5	≤-22

Ideally, the core diameter and the cladding diameter of two spliced fibers should be same; however, this hypothesis will not happen because of the different manufacture qualities of fiber provider. After an experimental investigation, the proposed arc discharge model above has been proved to get a good splicing performance for two kinds of typical splicing situations: the instance of cladding diameter mismatch and the instance of core offset. The former splicing situation means the cladding diameters of two fibers are different; while the latter situation stands for the axis of fiber core are different. In theory, the splicing loss of those situations can be calculated by (11). In practical application, the computation result of equation (11) can only be regarded as a reference for the splicing loss estimation of spliced fiber.

$$\alpha_1 = 10 \times \lg \left[ \left( \frac{2ab}{a^2 + b^2} \right)^2 \exp \left( -\frac{2d^2}{a^2 + b^2} \right) \right] \quad (11)$$

where  $a$  and  $b$  are the mode field diameters of two fibers;  $d$  is the offset of fiber cores.

To illustrate the effectiveness of the proposed method, the splicing loss, the extinction ratio, and the maximum tensile strength of splicing point are measured before and after the improvement of the arc discharge model. Fig. 5 shows the comparison result examples of the splicing loss and the maximum tensile strength of splicing point. Where (a) is the test experiment result of splicing loss, and (b) is the experiment result of the maximum tensile strength. Here, the “traditional method” is the splicing method which uses the arc discharge model in Fig. 2; while “the proposed method” is the design method which employs the arc discharge in Fig. 3. The core diameters of spliced fibers are about 3.25μm and 4.75μm, respectively. From Fig. 5 (a) and (b), after the improvement of arc discharge function, the splicing loss will be decreased about 42.9%; while the tensile strength of the splicing point will be increased about 59.6%. The similar result of extinction ratio can also be gotten: the extinction ratio can be increased about 37.2%.

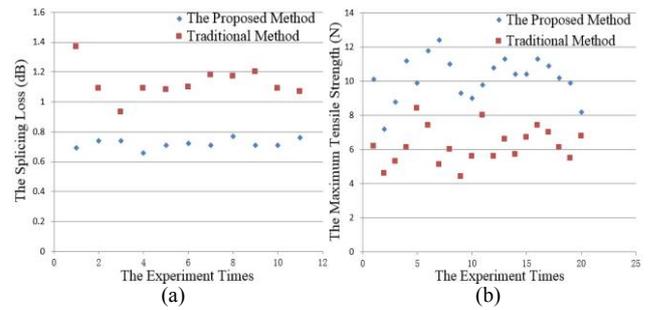


Fig. 5. The comparisons of splicing loss and tensile strength of splicing point before and after the improvement of the arc discharge model

The reliability index reflects the lifetime and the fault ratio of the spliced fiber. In general, it can be modelled by the Weibull distribution. The parameters  $m$  and  $\eta$  of Weibull can be estimated by the mechanics experiment and the distribution estimation techniques. In a practical engineering application, the fiber fracture is intolerant for any fiber based systems, thus the reliability index is important for the quality assessment of splicing point. As for an optoelectronics system, the fiber will be used as a transmission media, multiple splicing points coexist in an optoelectronic system. For example, an IFOG product will include at least 20 splicing points. Thus the integrated evaluation of multiple splicing points should be considered. Fig. 6 shows the computed results of reliability index under a normal environment condition: (a) is the reliability of single spliced point, here  $m_1=1.13$ ,  $\eta_1=4.89$ ; while (b) is the reliability of three series spliced points, here  $m_1=1.13$ ,  $\eta_1=4.89$ ,  $m_2=1.07$ ,  $\eta_2=4.30$ ,  $m_3=1.57$ ,  $\eta_3=5.12$ . The lifetime of spliced fiber is affected by the environment factors, such as the temperature, the humidity, or the stress. Thus the parameter estimations of Weibull

distribution under different environment experiments should be carried out.

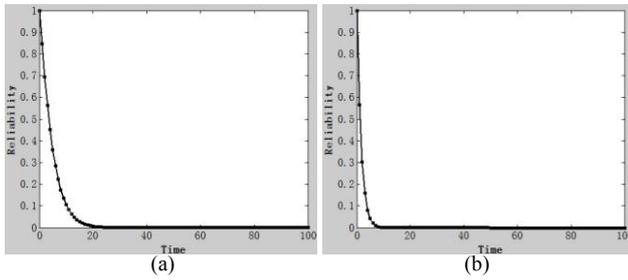


Fig. 6. The computation results of Weibull distribution based fiber splicing reliability

To test the splicing quality further, the spliced fibers are assembled into an IFOG product, the SVM is implemented as an indirect assessment tool of splicing quality evaluation. The indexes including the splicing loss, the extinction ratio, the maximum tensile strength, and the Weibull distribution based reliability index, are regarded as training data of SVM; and the zero bias is regarded as supervising data of SVM to evaluate the assembly quality. Only the binary classification problem is considered: the qualified IFOG product and the unqualified IFOG product. About 200 data are employed to train SVM because of its low requirement for training data but good performance for forecast effect. Table 2 shows the computation results of SVM. In Table 2, first, only the traditional splicing evaluation indexes, i.e., the splicing loss and the extinction ratio, are used to evaluate the integrated splicing effect. Second, all the four proposed indexes in this paper are used to evaluate the splicing effect. From Table 2, our proposed method can get a better calculation effect. This result can be explained as: because more features are utilized, the forecasting performance of SVM can be improved.

Table 2. The integrated splicing quality comparison of IFOG by using SVM classifier

Training Data of SVM	Classification Accuracy
Splicing Loss and Extinction Ratio	89% ( $\gamma_1$ )
Splicing Loss, Extinction Ratio, Tensile Strength of Splicing Point, and Reliability Index	94% ( $\gamma_2$ )

In this paper, many environment worthiness experiments are also used to test the performance of spliced fiber. The environment worthiness experiments include the temperature store experiment, the temperature cycle experiment, and the random vibration experiment. The index of Lot Tolerance Percent Defective (LTPD) [23] is used to sample the splicing product. All the control parameters of different experiment conditions are shown in Table 3. The temperature store experiment stores the spliced fiber under the extreme temperature environment,

including the high temperature environment and the low temperature environment. The temperature cycle experiment tests the tolerance character of fiber material under a changeable temperature. The random vibration experiment will check the splicing intensity of splicing point considering of typical impulsion and vibration. Thirty three spliced points are utilized to take part in all the environment worthiness experiments. After the test of practical experiments all the spliced fibers which use the proposed splicing technique do not meet any quality problems. However, in the past the quality problem will appear here and there during those worthiness experiments. These experiment results can indicate the validity of proposed splicing technique.

Table 3. The reliability experiments and the corresponding experiment conditions

The high temperature store experiment		The temperature cycle experiment		
Temperature (°C)	Store time (h)	Temperature (°C)	Store time (h)	Temperature (°C)
65	2000	65	2000	65
The low temperature store experiment		The vibration experiment		
Temperature (°C)	Store time (h)	Temperature (°C)	Store time (h)	Temperature (°C)
-25	2000	-25	2000	-25

Many factors will influence the final splicing effect of fiber splicer, such as the fiber axial offset, or the fibers axial inclination, etc. After an experimental study, some summaries about the fiber splicing process can be made. First, the splicing time and the electrical intensity of the pre-discharge will decide the splicing quality of spliced fiber end face. If their setting values are improper the splicing defect will appear easily. Second, the end face distance with large scope needs a big intensity of arc discharge; while the end face distance with small scope only needs a small intensity of arc discharge. This conclusion can be understood by the fact that the larger electrical power will create bigger arc discharge field through the electrodes. Third, the extrusion length of the fibers will influence the diameter and quality of the fiber splicing point. If the extrusion length is too large, the inner core and the fiber stress region may be crushed; and the distortion, the deformation, or the poor optical character can be observed in that situation. If the extrusion is too small, the diameter of splicing point will be small or even broken, and the tensile strength of splicing point will also be poor.

When evaluating the splicing effect of fibers, the proposed experiments demonstrate: first, many splicing features should be considered to evaluate the splicing effect. Because the practical application is complex, in many cases the essence of typical fiber splicing process cannot be recognized or measured easily; as a result, it is necessary to develop some new analysis and measurement methods for the spliced point. Second, the big data processing technique should be developed to analyze the

assembly data and improve the splicing quality. The classifier, such as the SVM or the Adaboost [24] classifiers have been proved to be good forecasting and classification tools; in future, those tools can exert good functions for the quality evaluation and control of complex optoelectronics product. Third, the environment test experiment is an essential measurement to evaluate the splicing effect or even the integrated product quality. Because our knowledge on the environment worthiness is limited, and no simulation theory or software can be used to evaluate the environment worthiness of complex optoelectronics product currently; as a result, it is also necessary to develop a series of practical experiment measurement to test the performance of complex splicing process technique in future.

## 6. Conclusion

In this paper, a new arc discharge model for the splicing process of a kind of PM fiber is proposed. The mathematic form of arc discharge function and the movement control method of spliced fibers are designed. The evaluation indexes, including the splicing loss, the extinction ratio, the maximum tensile strength, and the Weibull distribution based reliability index of splicing point, are all utilized to assess the splicing effect. The SVM classifier is used to assess the integrated splicing quality of IFOG. Two cases of the splicing situations, i.e., the case of cladding diameter mismatch and the case of core diameter mismatch can be solved well by the proposed method. According to the environment worthiness experiments, the proposed process techniques also behave a good performance. In the next research step, the splicing process technique to other fiber type will be developed.

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## References

[1] S. Koike, S. Asakawa, M. Kobayashi, R. Nagase, J. Kobayashi, K. Uesugi, K. Kajiwara, A. Takeuchi, Y. Suzuki, I. Hirose, Y. Watanabe, *IEEE Trans. Compon. Packag. Manuf. Technol.* **1**, 100 (2011).

- [2] W. C. Wong, C. C. Chan, Y. F. Zhang, K. C. Leong, *IEEE Photonics Technol. Lett.* **24**, 359 (2012).
- [3] G. Keiser, *Optical Fiber Communications*, McGraw-Hill Higher Education Press, 3rd, (2000).
- [4] H. Liu, W. Wang, X. Li, F. Gao, *Chin. Opt. Lett.* **11**, 101501 (2013).
- [5] C.-D. Chang, S.-M. Chuo, L. A. Wang, *SPIE* **7753**, 775367 (2011).
- [6] M. Kihara, R. Koyama, Y. Abe, H. Son, M. Kobayashi, S. Tomita, *Opt. Fiber Technol.*, **19**, 269 (2013).
- [7] Y. Chang, H. Liang, J. Li, L. Cheng, B. Guan, *SPIE* **8421**, 84217A (2012).
- [8] Z. Sun, N. Song, J. Jin, J. Song, P. Ma, *Opt. Fiber Technol.*, **18**, 452 (2012).
- [9] H. Liu, W. Wang, F. Gao, J. Li, K. Chen, *Infra. Phys. Technol.*, **66**, 125 (2014).
- [10] H. Parsaei, D. W. Stashuk, *IEEE Trans. Biomed. Eng.*, **59**, 183 (2012).
- [11] W. Wang, *Introduction of the Interferometric Fiber Optic Gyroscope Technology*, 1st ed., China Aerospace, Beijing (2010).
- [12] E. Pecht, M. P. Mintchev, *IEEE Trans. Instrum. Meas.* **56**, 1935 (2007).
- [13] Z. Chen, X. Xi, W. Zhang, J. Hou, Z. Jiang, *J. Lightw. Technol.*, **29**, 3744 (2011).
- [14] M. Miyazaki, M. Mizutani, H. Shimoyama, M. Kurokawa, Y. Okawa, *IEEE Trans. Compon., Hybrids, Manuf. Technol.*, **13**, 807 (1990).
- [15] B. S. Wang, E. W. Mies, *SPIE* **6781**, 678130 (2007).
- [16] W. Zheng, B. Malinsky, *SPIE* **8237**, 82372E (2012).
- [17] C.-D. Chang, S.-M. Chuo, L. A. Wang, *SPIE* **7753**, 775367 (2011).
- [18] G. V. Guinea, M. Elices, C. Rossello, *Eng. Fracture Mech.*, **69**, 1057 (2002).
- [19] Y. Abe, H. Hirota, S. Asakawa, J. Kobayashi, *Electronics Lett.*, **48**, 641 (2012).
- [20] H. Chen, M. Leblanc, *IEEE Photonics Technol. Lett.* **16**, 2198 (2004).
- [21] H. Guo, H. Liao, *IEEE Trans. Reliab.*, **61**, 231 (2012).
- [22] X. Liu, Z. Li, *Math. Theory Appl.*, **34**, 125 (2014).
- [23] A. Namenson, D. Myers, *IEEE Trans. Nucl. Sci.*, **40**, 1709 (1993).
- [24] C. Kyrhou, T. Theocharides, *IEEE Trans. Very Large Scale Integr. (VLSI) Syst.*, **19**, 1034 (2011).

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