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Ultraviolet Sensor based on Micro-nano Fiber Coupler

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Abstract

Partial discharge measurement is an effective means to diagnose insulation deterioration of electrical equipment. electric pulse, electromagnetic radiation, wave, light, gas generation and so on will be produced in the process of partial discharge, and energy loss can be produced to cause local overheating. the state of partial discharge can be characterized by describing the physical quantity of the phenomenon.a micro-nano fiber coupler is prepared by using a fiber-melting taper machine, which reduces the experimental cost and operation difficulty. the spectral changes of the micro-nano fiber coupler in the ultraviolet range between 0~12mWcm-2 are measured. With the increase of UV intensity, the influence of different UV intensity on the output wavelength is analyzed. Experiments show that the UV sensor made by micro-nano fiber coupler can be used as a new optical fiber sensing measurement method in partial discharge detection.

Keywords

Partial discharge measurement; UV sensor; a micro-nano fiber coupler; fiber-melting taper machine.

1. Introduction

With the rapid development of national power system, the stability and reliability of power equipment are more and more demanding.The insulation performance of power equipment itself is an important standard for the safety and reliability of power equipment, but due to the external force, overload, ultraviolet and other factors that may damage the insulation performance of power equipment during the operation of power equipment for many years, partial discharge of electrical facilities in power network is a common phenomenon.When partial discharge occurs, it is often accompanied by various physical and chemical phenomena such as electric pulse, electromagnetic radiation, light, ultraviolet, ultrasonic wave and gas. The state of partial discharge is characterized by describing the physical quantity of the phenomenon. The corresponding detection methods include pulse current method, gas chromatography, ultrasonic method, radio interference detection method, optical measurement method and so on [1].

At present, the most widely used methods are pulse current method and ultrasonic detection method. Rogowski coil current sensor is commonly used in pulse current method[2,3]The measurement of signals in the radio frequency band (3-30 MHz) of partial discharge is also recommended in the National Standard GB/T7354-2003 Partial Discharge Measurement [4] However, due to the existence of many electromagnetic interference in the field, such as power system carrier, communication radio broadcast interference, high frequency protection signal, power system harmonic interference and some interference caused by the operating characteristics of the equipment itself, this method can avoid a large number of low and medium frequency interference in the field, but it is difficult to avoid a large number of interference in the radio frequency range. Ultrasonic detection is aimed at the ultrasonic

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frequency component of 70-150 kHz in high voltage local discharge, but because this part of ultrasonic energy attenuates quickly, and because the efficiency of acoustic-electric energy exchange element is not high enough, this detection technology is often combined with radio interference and other detection methods.At this time, the optical fiber sensor measurement method can be used to diagnose the partial discharge fault of power equipment.

SiO_2 is the main material for fiber optic sensors, excellent insulation performance, strong electromagnetic interference resistance, this advantage is particularly prominent in ultra high voltage, ultra high voltage power systems.Moreover, the optical fiber sensor has the advantages of small size, high sensitivity, fast response speed, digitalization, flexible arrangement, and deep detection in power equipment without affecting its working state, such as integration with transformer and other equipment.Because of the advantages of distributed measurement, long distance transmission and other electrical sensors, optical fiber sensor detection method has a wide application prospect in the field of partial discharge measurement of power equipment[5]

Optical fiber and waveguide couplers are the basic devices for optical system integration and other functional optoelectronic devices. With the rapid development of micro-nano fiber processing technology in recent years, new sensors made of micro-nano optical devices have been developed accordingly. Compared with traditional fiber, micro-nano fiber has better optical and mechanical properties, such as large evanescent field, strong light binding, flexible compounding and low loss[6-8]It has the corresponding characteristics of micro-nano-photon devices, which makes it have great research value in the development of new micro-nano-optical devices and so on[9-11]The fabrication methods of micro-nano fiber coupler mainly include micro-nano fiber lap method based on evanescent field coupling and double fiber direct stretching method. The structure and properties of micro-nano fiber coupler prepared by double fiber direct stretching method are better than that of micro-nano fiber lap method. Micro-nano fiber coupler has been used for wide spectrum single mode transmission [12]and other physical parameters such as UV, refractive index and vibration [13-15] When partial discharge occurs, it is accompanied by UV changes. This paper introduces the preparation of micro-nano fiber coupler by double fiber melt stretching method. The UV sensing performance of micro-nano fiber coupler is tested by experiments. The results show that There is a good linear relationship between the interference wavelength shift and the change of UV intensity, and a sensitivity of 0.07nm/mWcm^{-2} was obtained.

2. Micro-nano Fiber Coupler Principle

a micro-nano fiber coupler (OMC), formed by melt stretching of two fibers, is composed of two conical transition zones, one intermediate uniform waist zone and four tail fiber ports, as shown in Fig. 1.

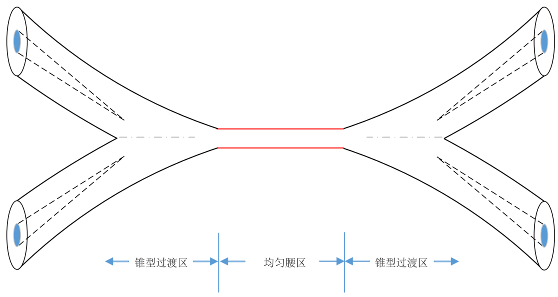

Fig. 1 micro-nano fiber coupler

due to the strong fusion characteristics of the micro-nano fiber, the coupler theory is applied to the coupling characteristics analysis of the micro-nano fiber coupler. the total coupling of the micro-nano fiber coupler is the superposition of the coupling of the transition region and the

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uniform waist region. the coupling characteristics are determined by the conical transition region and the uniform waist region. Preliminary approximate theoretical analysis using a simple analytical method [16].

Under this condition, the coupling coefficient of the micro-nano fiber coupler can be expressed as:

$$C(\lambda)=\frac{3\pi\lambda}{31a^{2}n_{1}}\cdot\frac{1}{\left(1+\frac{1}{V}\right)^{2}}$$

Among them, λ is the wavelength of the incident light, a is the diameter of the effective coupling part of the fiber, and V is the normalized frequency expression of the fiber, which can be expressed as the refractive index of the fiber core and the surrounding medium:

$$V=\frac{2\pi a}{\lambda}\sqrt{n_{1}-n_{2}}$$

The output power of the two tail ports is:

$$\begin{cases}P_{3}(l)=P_{0}\cos^{2}(CL)\\ P_{4}(l)=P_{0}\sin^{2}(CL)\end{cases}$$

In the formula, the input optical power is the effective coupling length. According to the above two formulas, the coupling ratio of micro-nano fiber coupler is related to the refractive index of the fiber core, the refractive index of the surrounding medium, the effective coupling length and the diameter of the corresponding fiber.

When the ultraviolet of the environment around the micro-nano fiber coupler changes, the refractive index changes with the ultraviolet of the surrounding environment, and the inclination wavelength and intensity of the output spectrum are sensitive to the change of ultraviolet[14,17].Therefore, the wavelength change of the output spectrum can be detected to realize the function of ultraviolet sensor.

3. Preparation of Micro-nano Fiber Couplers

Compared with traditional fiber couplers, micro-nano fiber couplers have a high evanescent field effect, which can couple part of the light energy from the waveguide mode to the evanescent field in the external environment [18] direct interaction with the outside world [19] When the external environment changes, it will affect the optical signal transmission in the fiber. Therefore, the optical fiber sensor with high sensitivity can be prepared by using this advantage of micro-nano fiber coupler.

In this paper, micro-nano fiber couplers are prepared by melt stretching method with short operation time, controllability and low optical signal transmission loss.The SMF-28e single mode fiber, fiber melting taper machine, broadband light source (Amplified Spontaneous Emission ：ASE) with center wavelength of 1550 nm and spectrometer (Optical Spectrum Analyzers ：OSA) are selected by Corning Company.Two single mode fibers are placed on the translation table so that the two fibers are as close as possible. The output end of the fiber coupler with a light ratio of 50:50 is removed from the fiber melting taper machine and inserted into the spectrometer. Adjust the spectrometer parameters and continue to stretch the fiber coupler. in order to protect the uniform waist part of the optical fiber, the quartz plate with 42 mm length should be used in the package, and the quartz plate at both ends of the quartz substrate should be encapsulated with 353 ND AB glue. When the color of the glue changed from transparent to brown, the glue solidified.

4. Results

According to the prepared micro-nano fiber coupler, the experimental optical path is built, the optometry is tested, and the ultraviolet detection and sensing experiment is carried out. Fig. 2 shows the optical path structure In order to reduce the influence of external vibration and airflow on the accuracy of the experimental results, the optical experimental instruments used are fixed on the seismic optical platform, and the optical path system is connected according to the diagram.The left side of the experimental optical path is a broadband light source (ASE) and a AQ6370D spectrometer (OSA).By adjusting the output power of the broadband light source for 5 mW, the optical fiber used is a single mode fiber, so as to control the ultraviolet change of the surrounding environment of the micro-nano fiber coupler.

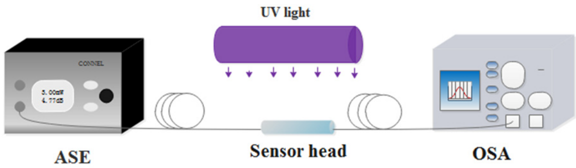

Fig. 2 Straight-through optical path

The transmission spectrum needs to be recorded after the spectral stability of the spectrometer. The transmission spectrum is shown in Fig. 3. With the increase of ultraviolet in the surrounding environment of the micro-nano fiber coupler, the interference peak wavelength shifts.

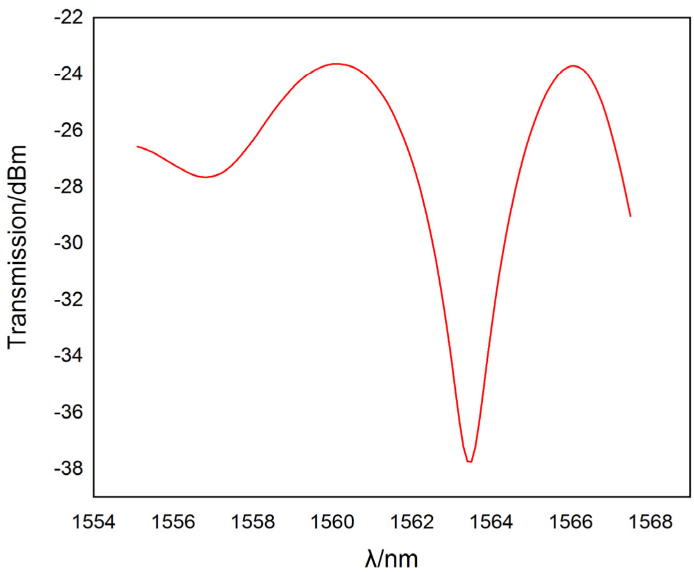

Fig. 3 Transmission spectrum

5. Analysis and Discussion

In this paper, the preparation process of micro-nano fiber coupler is introduced in detail. Two single-mode fibers are fused and stretched to form a micro-nano fiber coupler structure by using a fiber melting taper machine, which reduces the experimental cost and operation difficulty, and improves the experimental efficiency. the UV sensor of micro-nano fiber coupler is prepared by using evanescent field principle. The change of transmission spectrum was measured, and the change law of different ultraviolet and spectrum was established. The experimental results are shown in Fig. 4, it shows that the wavelength of the interference spectrum of the prepared UV sensor drifts within 0-12mWcm^{-2}, showing good sensitivity of 0.07nm/mWcm^{-2}. The results show that the wavelength of the interference spectrum of the prepared UV sensor is shifted the experimental results can provide a reference for sensing applications based on micro-nano fiber couplers.

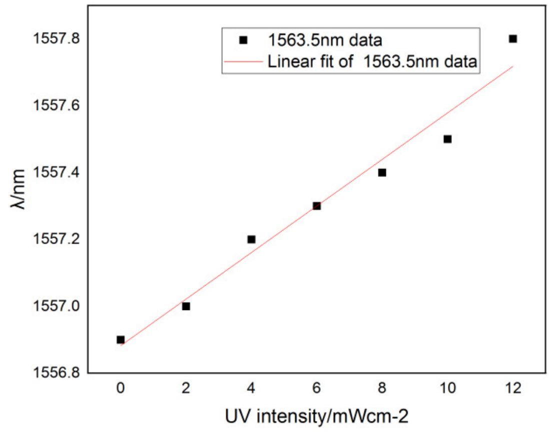

Fig. 4 Experimental result

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