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# Resolution enhancement of Fabry-Perot optical fiber probe for microstructure measurement

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**Abstract**

In recent years, there has been an increase in the number of devices with fine and high-aspect-ratio microstructures in the fields of semiconductors, optical communications, medicine, biotechnology, Micro Electro Mechanical Systems (MEMS), micromachines, and various nozzle holes. There is an increasing demand for precise, nondestructive measurement of the dimensions and surface roughness of these devices in order to enhance the functionality of products. Therefore, we propose an optical fiber probe to detect contact with a measured surface by incorporating a Fabry-Perot interferometer into an optical fiber tip. This paper describes the configuration of the Fabry-Perot fiber probe for microstructure measurement. Simulation results then confirmed that the wavelength shift corresponding to the measurement resolution was increased by approximately 6.9 times by making a film of the elastic resin of the reference probe 10 µm thicker than that of the measurement probe.

Microstructure measurement; Probe; Optical fiber; Fabry-Perot interferometer, Vernier effect

## 1. Introduction

In recent years, there has been an increase in the number of devices with fine and high-aspect-ratio microstructures in the fields of semiconductors, optical communications, medicine, biotechnology, Micro Electro Mechanical Systems (MEMS), micromachines, and various nozzle holes. There is an increasing demand for precise, nondestructive measurement of the dimensions and surface roughness of these devices in order to enhance the functionality of products [1-2]. We have developed a measurement system using small diameter optical fiber as probe [3-5]. However, when the diameter of probe shaft is less than a few µm, the laser spot diameter at the laser irradiation point becomes larger than the shaft diameter, which causes diffraction of the laser beam, which results in a problem of reduced sensitivity. Therefore, we propose an optical fiber probe to detect contact with a measured surface by incorporating a Fabry-Perot interferometer into an optical fiber tip. This paper introduces the measurement principle of the probe and simulation results of measurement resolution enhancement using the vernier effect.

## 2. Measurement priciple

Based on past measurement results, the resolution of probe was about 20 nm. However, some measurement objects require a measurement resolution of 10 nm or less. Therefore, we try to enhance the measurement resolution by using the vernier effect. Figure 1 shows a schematic diagram of the Fabry-Perot optical fiber probe and its optical system. Light $I_{in}$ irradiated from a broadband SLD light source enters the measurement and reference probes with 1:1 light intensity via single-mode fiber and coupler. The fiber probe consists of the gold half mirror SM1, the elastic resin, and the probe tip coated with a gold half mirror SM2, in that order. The reference probe consists of the gold half mirror RM1, the elastic resin, and the glass substrate coated with a gold half mirror RM2, in that order. A Fabry-Perot interferometer is configured between the half-mirrors at the tip. The reflected lights $I_{out\_S}$ and $I_{out\_R}$ from the Fabry-Perot interferometer of the measurement and reference probes are again received by the spectrum analyzer via the coupler. The spectrum of the interference light received by the spectrum analyzer varies with the thickness of the elastic resin. In other words, the thickness of the elastic resin changes when the probe tip contacts the measured surface, making it possible to detect contact by measuring the spectrum of the reflected light (*e.g.*, the amount of shift in the peak wavelength). The light $I_{out\_S}$, which is the interference light between the light $I_{S1}$ reflected by the half-mirror SM1 and the light $I_{S2}$ reflected by the half-mirror SM2 coated on the probe tip for measurement, and the light $I_{out\_R}$, which is the interference light between the light $I_{R1}$ reflected by the half-mirror RM1 and the light $I_{R2}$ reflected by the half-mirror RM2 coated on the glass substrate for reference, respectively, interfere at the coupler, and the interference light $I_{out}$ is received by the optical spectrum analyzer (OSA).

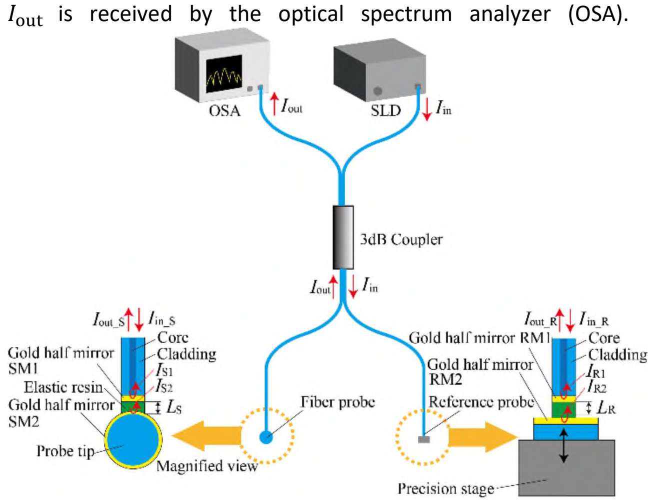


**Figure 1.** Schematic diagram of the Fabry-Perot optical fiber probe and its optical system.

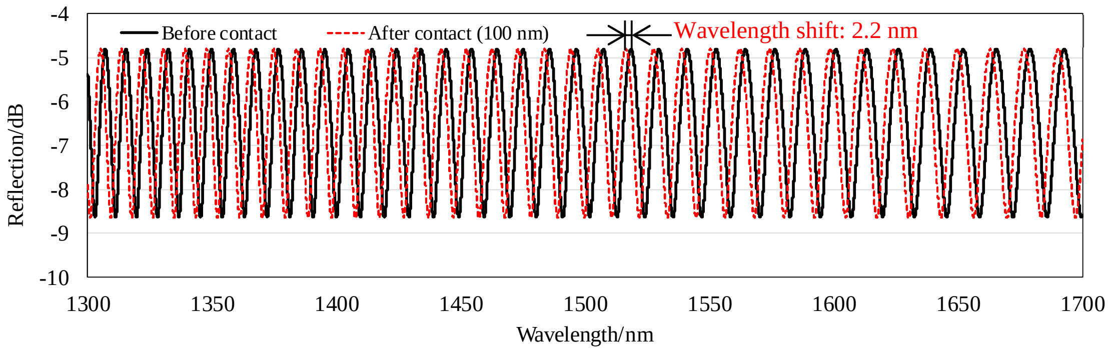


**Figure 2.** Interference spectra before and after contact without vernier effect.

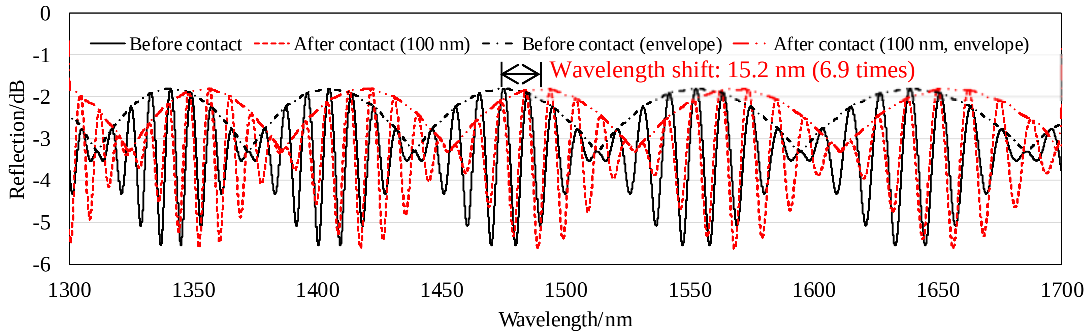


**Figure 3.** Interference spectra before and after contact with vernier effect (thickness difference: 10 μm).

## 3. Resolution enhancement using vernier effect

The interference light intensity $I_{\text{out}}$ can be expressed by Equation (1).

$$I_{out} = I_{\text{out\_S}} + I_{\text{out\_R}}$$
$$= I_{\text{S1}} + I_{\text{S2}} + I_{\text{R1}} + I_{\text{R2}} + 2\sqrt{I_{\text{S1}} + I_{\text{S2}}} \cos\phi_1$$
$$+2\sqrt{I_{\text{R1}} + I_{\text{R2}}} \cos\phi_2 \quad (1)$$

$\lambda$: Wavelength of incident light, $n$: Refractive index of elastic resin, $L_{\text{S}}, L_{\text{R}}$: Film thickness of elastic resin, $\phi_{\text{S}}, \phi_{\text{R}}$: Initial phase of interference

The interference spectrum without the vernier effect, i.e., without the reference probe in Figure 1, is shown in Figure 2. The solid line shows the spectrum when the probe tip does not contact the measured surface, and the dashed line shows the spectrum when the probe tip comes into contact with the measured surface and the elastic resin film thickness then decreases by 100 nm. It can be confirmed that the spectrum is shifted by about 2 nm due to contact. Next, Figure 3 shows the interference spectrum when the vernier effect is utilized with the optical system in Figure 1. The thickness of the elastic resin of the reference probe was 10 μm larger than that of the measurement probe. Similar to Figure 2, the solid line shows the spectrum when the probe tip is not in contact with the measured surface, and the dashed line shows the spectrum when the elastic resin thickness decreases by 100 nm due to contact. The wavelength shift of the envelope of the interference signals reflected from the measurement and reference probes was calculated to be 15.2 nm, which is 6.9 times larger than that without the vernier effect, indicating that the vernier effect is expected to enhance the resolution by improving sensitivity.

## 4. Conclusions

This paper describes the measurement principle of the probe and simulation results of measurement resolution enhancement using the vernier effect. We confirmed that the wavelength shift corresponding to the measurement resolution was increased by approximately 6.9 times by making a film of the elastic resin of the reference probe 10 μm thicker than that of the measurement probe.

## References


[1] Michihata M 2022 Surface-sensing principle of microprobe system for micro-scale coordinate metrology: a review *Metrol.* **2**(1) 46-72

[2] Fang F Z, Zhang X D, Gao W, Guo Y B, Byrne G and Hansen H N 2017 Nanomanufacturing—Perspective and applications *CIRP Ann. - Manuf. Technol.* **66**(2) 683-705

[3] Murakami H, Murakami H, Katsuki A, Sajima T and Uchiyama K 2023 Development of a two-step stylus with elastic hinge for microstructure measurement to improve sensitivity and vibration characteristics *Precis. Eng.* **80** 72-81

[4] Uchiyama K, Murakami H, Katsuki A and Sajima T 2023 Development of a sharp-tipped L-shaped stylus for measurement of nanoscale sidewall eatures *Int. J. Autom. Technol.* **16**(4) 489-96

[5] Murakami H, Katsuki A, Sajima T, Uchiyama K, Yoshida I, Hamano Y and Honda H 2020 Development of measurement system for microstructures using an optical fiber probe: improvement of measurable region and depth *Meas. Sci. Technol.* **31**(7) 72-81