Erbium-doped dual wavelength fiber laser interferometric proximity sensor with ±16 nm measurement accuracy

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Abstract: An erbium-doped fiber ring laser proximity sensor with a high accuracy of ±16 nm, when the output power difference between the dual lasing wavelengths (~1560 nm) is smaller than 3 dB wavelength has been demonstrated.

1. Introduction

Measurements of fundamental physical parameters such as displacement, distance, acceleration, strain, temperature, and torque, for example, are important for the development of advanced measurement or manufacturing systems and usually can be made using optical interferometry, taking advantage of the high sensitivity and high accuracy available. Techniques in precision mechanics have been used extensively for developing cutting-edge techniques for the semiconductor and aviation industries, for example. Many of the devices considered have used for real-time, high accuracy measurement systems which are challenging to use and the optical proximity sensor and ruler are the essential devices to determine respectively the origin of the coordinate and the linear travelling range, along the *x, y, z, θ* axes for precision 5-axis mechanical machining. For proximity sensing, the current standard technique used involves a tungsten steel knife with a sharp and thin front edge. When the moving object comes to contact the knife edge and produces the electronic 'trigger' signal, the origin of the coordinate system used for the machining planned then can be determined. However, the accuracy of the machining is usually not less than 1 μm, in practical applications. The measurement resolution should be better than one tenth of the machining accuracy, according to the calibration rules. For example, an optical ruler with a 50 nm measurement resolution can allow a machining accuracy of 0.5 μm to be obtained. Therefore, in order to achieve a precision in the micromachining of better than 1 μm, high accuracy noncontact proximity sensors and optical rulers measuring to a few hundreds of nanometers are important. Fiber optic-based interferometers, especially Michelson [1] and Fabry-Perot [2] interferometers, are usually employed. However, the best spatial resolution is a half wavelength, allowing a resolution of ~750 nm, when a C-band light source is used.

To improve on this, in this work a novel noncontact erbium-doped fiber laser-based interferometric proximity sensor with a high accuracy of ±16 nm is proposed, potentially giving a better measurement result than with the mechanical tungsten knife method. The laser proximity sensor discussed involves incorporating an off-axis interferometer (OAI)[3], shown schematically in Fig. 1(a), into an erbium-doped fiber ring laser, as illustrated in Fig. 1(b). The optical characteristics of the OAI are measured using superluminescent diodes (SLD) spanning 1250-1650 nm as sources and an Optical Spectrum Analyzer (OSA). The typical interference spectrum obtained is shown in Fig. 1(c), where the wavelength beating can be observed since multiple cladding modes are involved in the optical interference effects seen. The free spectral range (FSR) between points A and B changes nonlinearly with the distance, *d*, between the mirror and fiber lens of the OAI, as shown in Fig. 1(d). When the mirror, shown in Fig. 1(a), is moved away for a few tens of nanometers, the oscillation curves, as well as the transmission peaks, change accordingly to generate the dual lasing wavelengths. When the output power difference between the dual wavelengths is close to zero, *d* is defined as the *proximity length*. For the operating lasing wavelength of 1560 nm, the proximity length is 49.05 μm from the desired object, since both the dual lasing wavelengths can be generated. The measurement accuracy achieved is ±16 nm: this being defined as the range when the output power difference between the dual lasing wavelengths is <3 dB. Such a noncontact laser interferometric proximity sensor is, in principle, highly accurate and is valuable as a tool to help achieve precision mechanical machining, of accuracy < 320 nm, which is much better than the current ~1 μm machining accuracy.

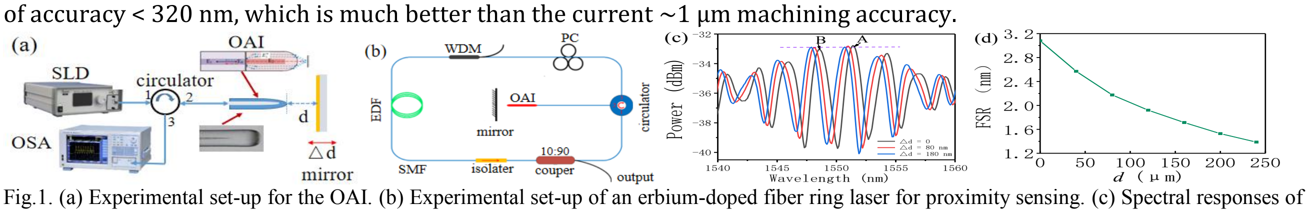

Fig.1. (a) Experimental set-up for the OAI. (b) Experimental set-up of an erbium-doped fiber ring laser for proximity sensing. (c) Spectral responses of the OAI when the mirror is moved. (d) FSR as a function of *d*.

2. Experimental set-up, measurements, and discussions

The OAI used was constructed by splicing a 231.7-µm-long hollow core fiber (HCF) to a standard single mode fiber (SMF). Fig. 1(a) shows an illustration of the side view of the OAI, whose working principle is to convert part of the core mode into cladding modes, at the splicing junction, since the HCF has a smaller core size than that of the SMF. The fiber lens helps deflect the cladding modes so that they focus at different positions along optical axis [3]. By incorporating an OAI into erbium fiber ring cavity with components including an isolator, a 10:90 tap coupler, a C-band circulator, a polarization controller, an Au-coated mirror, and a WDM coupler, the unidirectional lasing is seen to start at 1557.57 nm, shown as the black line in Fig. 2(a) when $d = 179.666$ µm. The C + L band erbium-doped fiber (EDF) is 10-meter in length. By moving the mirror away from the fiber lens, the laser spectrum changes, moving towards longer wavelengths with increasing d. To fine tune the mirror position, stable dual wavelength lasing can be achieved at 1557.46 nm and 1560.06 nm simultaneously, as shown in Fig. 2(b), and the position where $d = 49.05$ µm is defined as the proximity length. The corresponding 3 dB laser linewidths are 0.032 nm and 0.037 nm, respectively. The free spectral range is 2.6 nm and the output power can reach ~-8 dBm, with an optical resolution of 0.05 nm of OSA. To further move the mirror around the proximity length across a few tens of nanometers, the output powers of the dual laser wavelengths become unequal and the accuracy of the proximity length is here defined from the situation when the output power difference between the dual lasing wavelengths is <3 dB. From Figs. 2(c)-2(h), it can be seen that the accuracy achieved is ±16 nm, as the output power difference is close to, but still smaller than, 3 dB for $\Delta d = \pm 16$ nm (Figs. 2(c) and 2(f)). Such a result is more accurate than from the current method, employing a sharp and thin tungsten knife with the 5-axis machining. With Δd increasing bilaterally, the power difference increases to eventually extinguish one of the lasing wavelengths. In fact, the dual wavelength lasing occurs, ascribed to the beating phenomenon both in the wavelength spectrum and in the power distribution along the optical axis of fiber lens in the OAI. Such an erbium fiber laser interferometric proximity sensor, with a proximity length of 49.05 µm and an accuracy of ±16 nm (32 nm in total), can have an important role in industry in high precision mechanics. In principle, it can help to achieve a machining accuracy of less than 320 nm according to the calibration rules that the measurement accuracy should be better than one tenth of the machining accuracy.

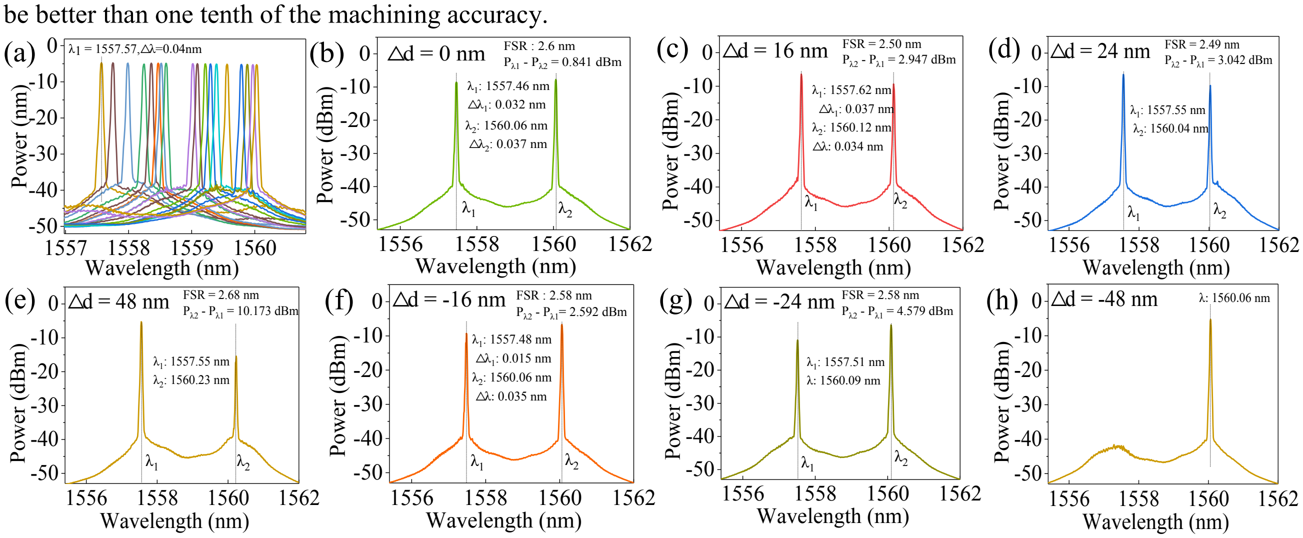

Fig. 2. Spectral responses of the laser proximity sensor for (a) single wavelength lasing situations with varying d and dual wavelength lasing situations with (b) $\Delta d = 0$ nm, (c) $\Delta d = 16$ nm, (d) $\Delta d = 24$ nm, (e) $\Delta d = 48$ nm, (f) $\Delta d = -16$ nm, (g) $\Delta d = -24$ nm and (h) $\Delta d = -48$ nm.

3. Conclusion

An erbium-doped fiber laser interferometric proximity sensor with a proximity length of 49.05 µm, achieving a measurement accuracy ±16 nm, has been demonstrated by incorporating an off-axis interferometer into a fiber ring resonator, at a lasing wavelength of 1560 nm. The off-axis interferometer shows a beating phenomenon both in the wavelength spectrum and power distribution, making the dual-wavelength lasing occur. The proximity length and the accuracy are respectively defined by the situation when the dual wavelength lasing occurs, with approximately equal output power and <3dB output power difference. This erbium fiber laser interferometric proximity sensor can have an important role in the high precision mechanics industry, to achieve a machining accuracy of less than 320 nm.

4. References

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