Development of a non-contact optical focus probe with nanometer accuracy

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Abstract: Non-contact type nano probes are normally sensitive to the property of measured surface. An optical focus probe that can achieve nanometer accuracy for any surface is presented in this paper. Extending from the previous work that adopted a commercial DVD pickup head as the sensor, this research devoted to the normalization technique of the focus error signal (FES) in association with the stabilized APC circuit design. The FES is detected by the four-quadrant photodiode when the reflective plane is away from the focal position. The normalization process can yield to the same FES curve for surfaces of different materials. By this means, the FES curve just needs to be calibrated once, and it can be used to scan across the surface which is composed of different materials. Installing this probe on a NMM (Nano Measuring Machine) and measuring some nano-scaled samples, results showed successfully with both accuracy and standard deviation about one nanometer.

1. Introduction

With the rapid development of micro system technologies and the increasing market need of various micro objects, the measurement system of 3D micro/nano profiles with nanometer accuracy is urgently demanded [1]. Currently, 3D micro/nano structures can be measured by some non-contact techniques to the nanometer accuracy, such as the hologram diffraction method [2], optical focus probe method [3], and SPM (Scanning Probe Microscope) methods [4]. They are all sensitive to the reflectivity of the measured surface and thus only limited to a single material at a time.

2. The operational theory of the focus probe

As shown in Figure 1, the auto power control (APC) technology is applied to make the laser diode to produce a 0.5mW and 650nm wavelength stable red laser beam. The laser beam diffracts into three beams when passing through a grating. Then these beams pass a polarized beam splitter, a quarter waveplate, and a collimator lens to transform the laser beams into a collimated beam. The collimated laser beam then passes through a PBS lens and a holographic Fresnel lens with concentric circular grooves to form a focus point on the surface of sample. When the light reflecting from the sample surface, the beams finally project onto the four-quadrant photodiode through the original path and a cylindrical lens, which will output A, B, C, D signals. Meanwhile, the sample and the beam spot could be observed by a CCD camera via the white light structure. According to the beam spot distribution among four quadrants, the FES (Focus Error Signal, ((A+C)-(B+D)) is used to measure the profile of the sample after proper signal processing.

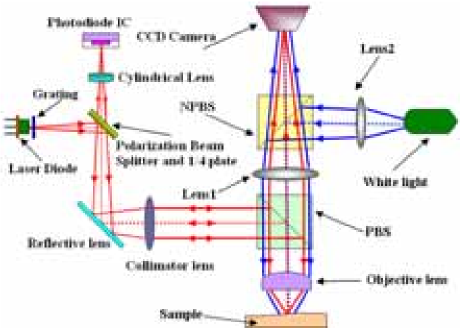


Fig.1: Focus probe configuration sketch

3. The normalization of S curve

For improving the application scope, the normalization of S-curve (NFES) is proposed in this paper. When the probe measures a sample surface with high reflective ratio, the NFES signal is:

$$S_H = [(A+C)-(B+D)]/(A+B+C+D) \tag{1}$$

If the probe measures a sample surface with low reflective ratio, the signals of the four quadrant sensors reduce K times at the same time, and the NFES is:

$$S_L = [(A/K + C/K) - (B/K + D/K)]/(A/K + B/K + C/K + D/K)$$
$$= [(A + C) - (B + D)]/(A + B + C + D) \quad (2)$$
$$= S_H$$

As shown in Eq. (2), the S-curve of sample surface with low reflective ratio is the same as the one of high reflective ratio. It proves that the probe could measure the 3D profile successfully no matter the surface contains any kind of material.

4. Calibration

Calibration of the focus probe with a standard step-height

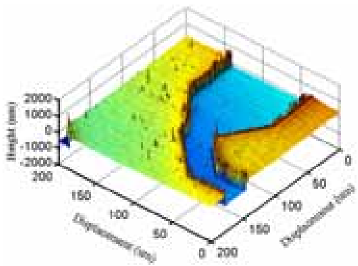
According to the international standard ISO-Norm5436 [5], in this experiment, the NMM carries the sample and moves the X-stage to allow the probe scan over the sample length. The data of the step-height measured 30 times along the same line. The compared results with different institutions are given in table 1. From table 1, it is seen that the deviation of NFES from PTB is only 0.3nm and the uncertainty is only 1.1nm.

Table 1: The comparison with different institutions

PTB calibration results with the expansion uncertainty (k=2)	Technische Universität Ilmenau calibration results with the expansion uncertainty (k=2)	HFUT calibration results with the expansion (FES) uncertainty (k=2)	HFUT calibration results with the expansion (NFES)uncertainty (k=2)
69.1±1.2	**68.4±0.8**	**69.0±1.6**	**68.8±1.1**

5. Measurements of composite materials

Some samples were measured to verify the measurement ability of NFES. Fgure14 shows the sample with white and black surface, figure15 shows the sample with mirror and transparent surface. All can be done by a single NFES S-curve.



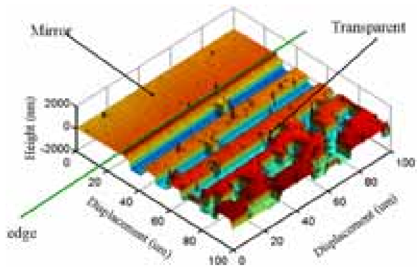


Fig.14: Sample (Nickel on ALGaN) Fig.15: mirror and transparent glass surface

Conclusion

The report proposed a new NFES method for the signal analysis of optical focus probe, which can be used from a commercial DVD. The normalization processing can be implemented by electronic circuit design. Having calibrated by a 3D nanomeasuring machine (NMM) and a standard step-height, a unique S-curve can be characterized to cope with different surface materials. Experimental results demonstrated the measurement capability of the probe for any composite micro/nano surface. Measurement resolution, accuracy, and uncertainty are all about 1nm level. It is a big advancement in nanometrology

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