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Probe Technologies for Micro/Nano Measurements

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1. Introduction

By definition, the nano-scale ranges from 100nm to 0.1nm. Any new development with size or function falls into this range is named "nanotechnology". The approach of nano-scale research can be in two ways: the bottom-up and the top-down. The bottom-up structure is built up with molecular particles and is the focus of science researches. The top-down approach is to miniaturize visible components from macro- to micro-size and finally downscale to nano-size. This is the way that the engineering technology can discover.

The mission of an engineer is to develop some technologies that can benefit to the industries. Most of the current industrial technologies still remain in the meso- to macro-scale level of the feature size. During the past decade, the MEMS (Micro-Electro-Mechanical System) and energy beam lithography technologies have attracted many researchers to the material processing in sizes from micro to high nano scales (100nm to 10nm). In order to follow the fashion, MEMS has been renamed to NEMS (Nano-Electro-Mechanical System) in recent years. The NEMS, however, can only provide manufacturing process in two and half dimensions (2.5D) through layer deposition, etching, etc. For the true 3D micro parts fabrication the concept of micro machine tools has to be realized. This is the new focus after the nanotechnology in the world, namely the "micro/nano system" (Ni, 2004; Sawada, 2007). A typical example can be found from Sasaki (2007) who successfully used an ultra-precision 5-axis micro-milling machine to cut a complex sculpture BOSATSU model in 2mm size.

It is understood that the metrology should always follow the step of manufacturing to ensure the quality of the products. For any 3D profile the 3D measurement must be employed. Conventional probes for dimensional measurement of parts in macro scale are no more capable for the meso- to micro- sized parts that require accuracy to the degree of 100nm to 10nm. The technology of micro/nano-scale 3D measurement is still a bottleneck for the industry.

This Chapter will address probe technologies for micro/nano measurements. Both of the non-contact and contact types of probes will be reviewed. For the non-contact probe, the principles and applications of focus probe and confocal microscope will be addressed. For

the contact type, the fabrication of micro probe with quality spherical tip will be introduced. A newly developed 3D touch probe for a micro-CMM (Fan, 2006) will be described.

2. Non-contact probes for micro/nano measurements

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. Currently, 3D micro/nano structures can be measured by some non-contact techniques to the nanometer accuracy, such as the hologram diffraction method, optical focus probe method, and SPM (Scanning Probe Microscope) methods. They are all sensitive to the reflectivity of the measured surface and thus only limited to a single material at a time. In this section, two types of non-contact probes are introduced. One is the focus probe, which is insensitive to surface material but only allows point measurement. The second is the confocal microscope for area measurement.

2.1 Focus probe

Laser focus probe is based on the astigmatic principle. Its optical path can be expressed by Fig. 1. A light from a laser diode is primarily polarized by a grating plate. Having passed through a beam splitter and a quarter wave plate (mounted on the beam splitter), it is focused by an objective lens onto the object surface as a spot approximately 1 μm in diameter, about 2 mm from the sensor. The reflected beam signal is imaged onto a four-quadrant photo detector within the sensor by means of the quarter wave plate. The photodiode outputs are combined to give a focus error signal (FES) which is used to respond to the surface variation. At the focal plane the spot is a pure circle. When the object moves up or down away from the focal plane, the spot appears an elliptical shape in different orientations. The corresponding focus error signal (FES) provides an S-curve signal proportional to the object movement, as shown in Fig. 2. Previous studies showed that on a single material, such as DVD disk, this probe can accurately measure 3D surface to nanometer accuracy (Fan, 2000; Mastylo, 2004). Products fabricated by NEMS process are, however, mostly built up different materials on the silicon substrate. Like other types of scanning probes, such as the hologram diffraction method or the SPM (Scanning Probe Microscope) methods, non-contact probes always have different characteristics curves with respect to different materials. A solution that utilizes the normalized FES (NFES) technique is proposed to cope with this problem.

When the probe measures a sample surface with high reflectivity, the NFES signal is:

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

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

$$\begin{aligned} S_L &= [(A/K+C/K)-(B/K+D/K)]/(A/K+B/K+C/K+D/K) \\ &= [(A+C)-(B+D)]/(A+B+C+D) \end{aligned} \qquad (2)$$

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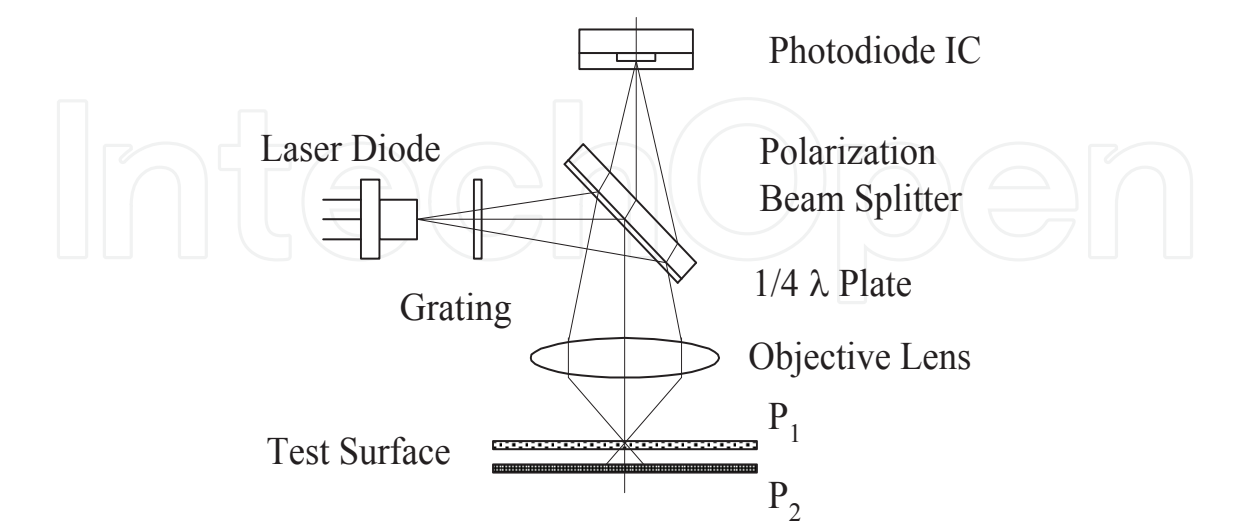

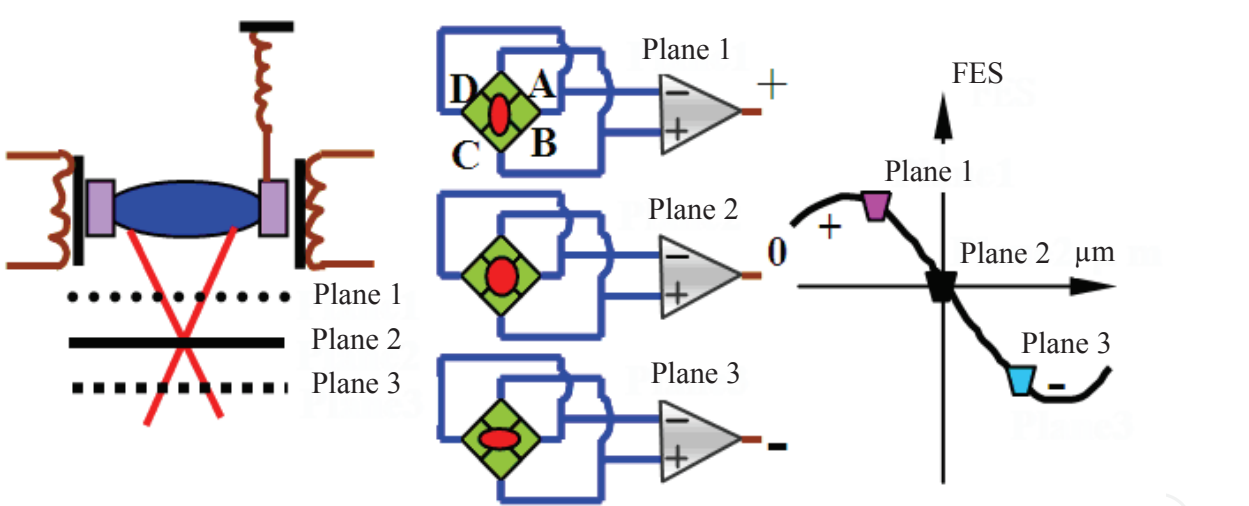Fig. 1. Optical system of the focus probe

Fig. 2. Focus error signal (FES) with respect to the distance

Calibration tests were conducted on different materials with the focus probe mounted onto a nanopositioning machine, made by SIOS Co. model NMM1 (Fan, 2007). Fig. 3 plots the calibrated FES and NFES curves of different materials. Due to the different reflective ratios each material has independent FES curve. After employing the normalization technique, all the NFES curves are almost the same. Measurement range is about 6μm, resolution is 1nm, and accuracy is about a few nanometers depending on the matrerial. Fig. 4 presents two measured samples, one is a MEMS part and the other one is a PTB step height of 69nm. The first case demonstrates the capability of measuring composite material. The second case verifies the accuracy of this probe.
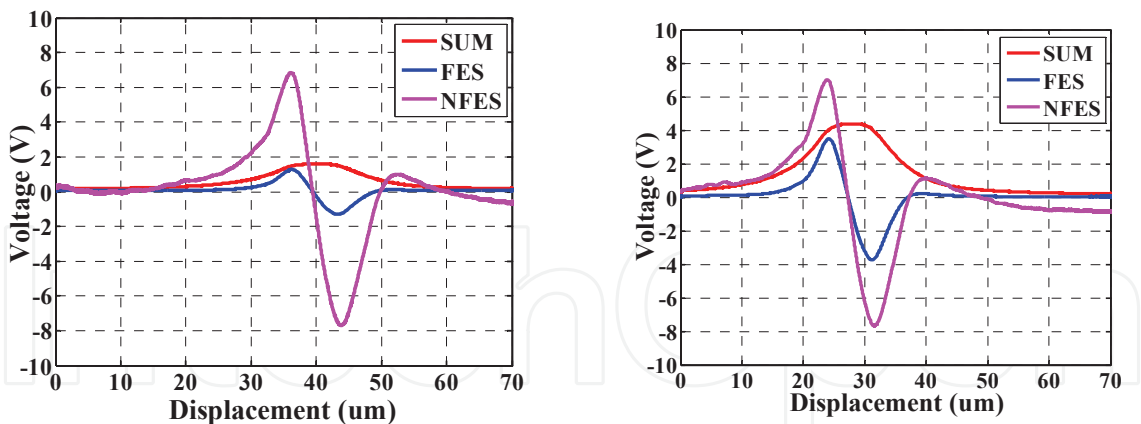
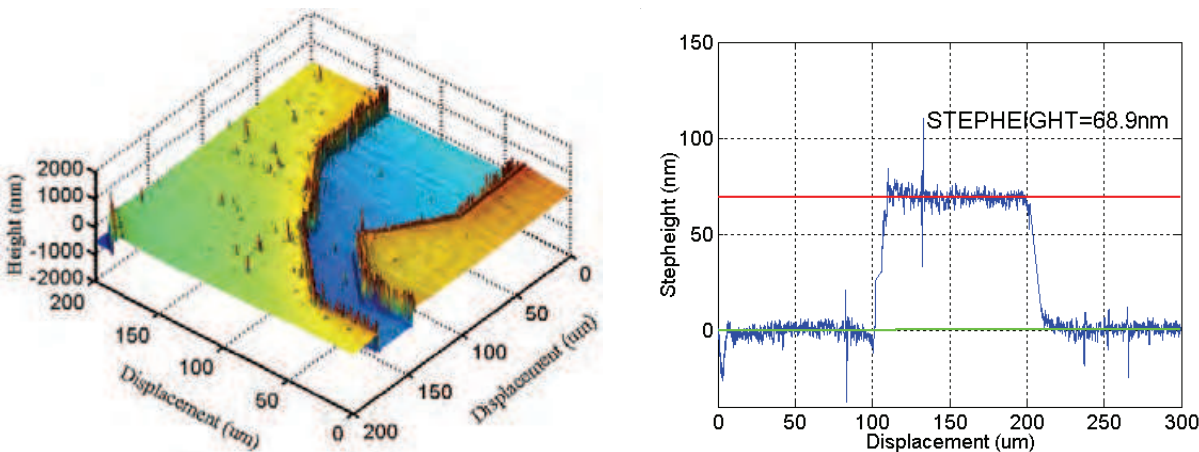Fig. 3. Calibrated FES and NFES curves for silicon surface (left) and mirror surface (right)

Fig. 4. Measured samples: MEMS Nickel on ALGaN (left) and PTB 69nm step height (right)

2.2 Confocal microscope

In recent years, the technique of confocal microscopy, first described by Minski (1957), has become a more and more powerful tool for surface characterization, in parallel with the development of computer-based image processing systems. The basic principle of confocal microscopy (Minski named it double focusing microscopy) is shown in Fig. 5. Light emitted from a point light source (for example a laser beam focused onto an illumination pinhole) is imaged onto the object focal plane of a microscope objective (the first focusing). A specimen location in focus leads to a maximum flux of light through the detector pinhole (the second focusing), whereas light from defocused object regions is partly suppressed. The variation of the detected intensity is a function of distance change. It, however, can only measure point by point. The white light confocal microscope was then proposed to measure one area profile at a time in conjunction with digital image processing technique. However, in order to detect the whole surface profile one more scanning principle has to be added, such as the point scan by rotating a Nipkow disk (Jordany, 1998) or the structure light projection method with DMD (Bitte, 2001).
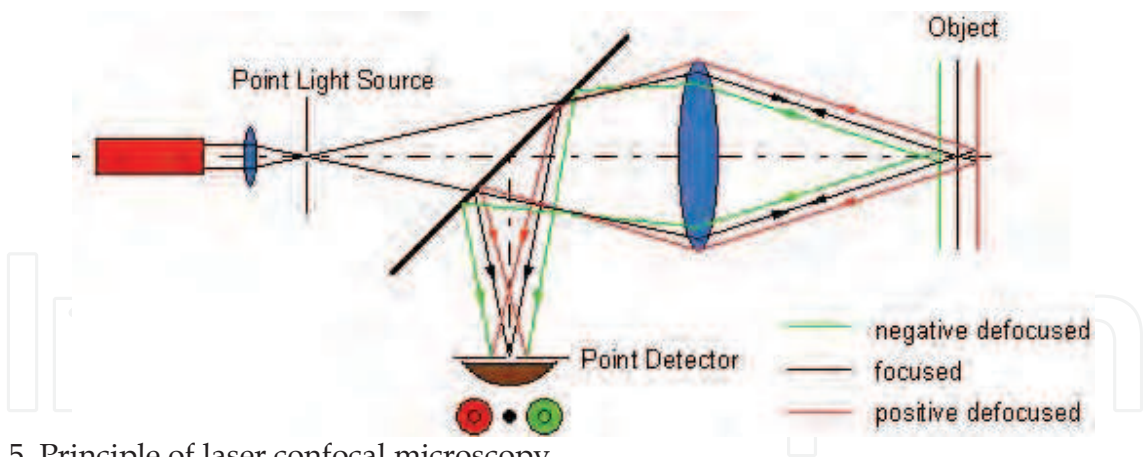
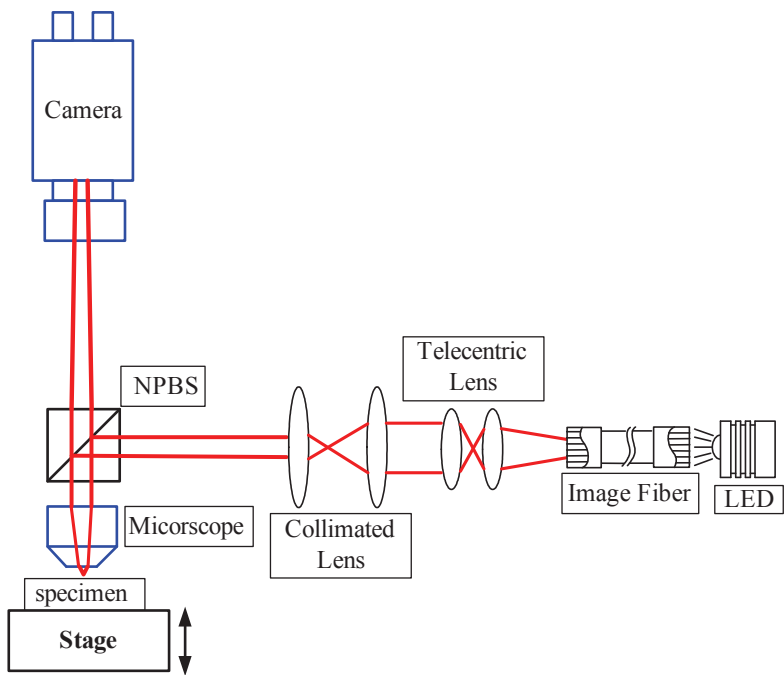Fig. 5. Principle of laser confocal microscopy

Fig. 6. Image fiber LED confocal microscope

A low cost confocal microscope probe for area detection has been developed (Fan, 2007). The system principle is shown in Fig. 6. It uses a high intensity LED to project light through an image fiber bundle onto the work surface. The fiber bundle consists of 80000 fibers with about 150μm in diameter each. The hexagonal grid pattern of the fiber bundle projected onto the work surface can be treated as a structural light. In the collected image frame the grey level change of the pixels is proportional to the distance out of focal plane of the probe. Fig. 7 shows an example of the photo spacer profile measurement on the LCD color filter plate. The result is the same as the one measured by a commercial white light interferometer. The thickness of the color filter's RGB film can also be obtained in the same graph. The accuracy of this fiber bundle confocal microscope relies on the accuracies of the positioning stage and the characteristic curve of the grey level vs. focal distance. Current system accuracy is about 100nm. It is low cost and suitable for micro level measurements.
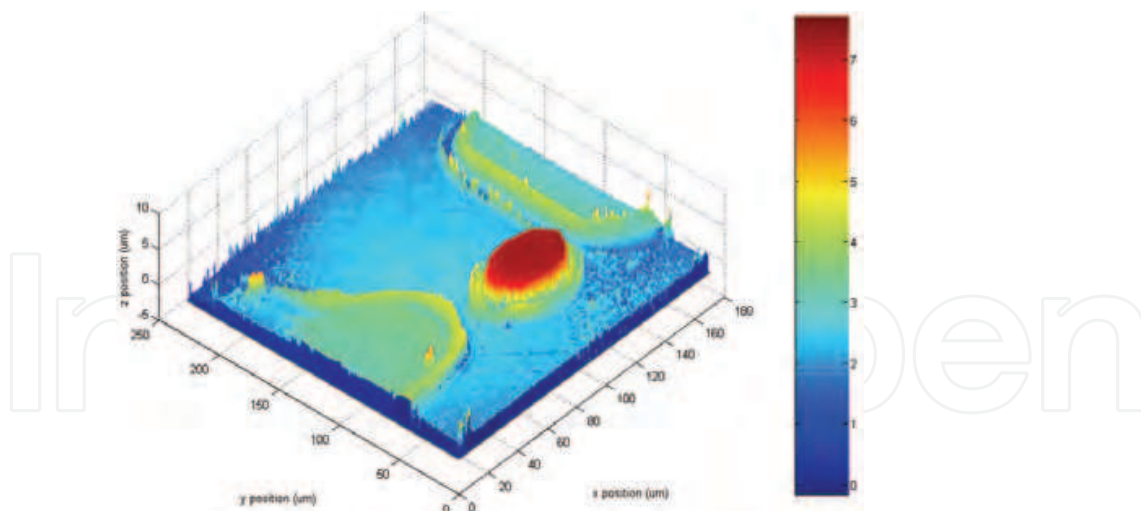
Fig. 7. Measured color filter film and the spacer

3. Contact probe for micro-CMM

3.1 The needs for contact probes

Ultrahigh precision 3D surface measurement technologies have been paid much attention in research during the last ten years. Although many non-contact measurement systems have been developed and commercialized successfully for meso- to micron- or micron- to nano-scaled 3D geometric measurement, such devices cannot cope with the side wall geometry measurement of high aspect ratio micro holes, grooves, and edges. The design and manufacturing of the contact probe becomes one of the critical factors to achieve the measurement capability. In addition, the probe only provides information at the moment of contact to the object being measured. To measure the full scale of any micro part, the object has to be precisely moved by an ultraprecision 3-axis positioner. Combining the contact probe system with the positioning system is generally called the coordinate measuring machine (CMM). Conventional CMM, as a versatile dimensional metrology tool, can only measure macro- to meso-scaled parts because of the size limitation of the probing system. The system design and integration of a contact type micro/nano-scaled three dimensional coordinate measuring machines (3D CMM) (Fan, 2006) has become increasingly important. This kind of micro-CMM requires higher measurement accuracy and resolution than conventional macro-scale 3D CMM.

Several researches have developed micro- or nano-CMM that can measure meso- to micro-scaled parts in nanometer resolution, mostly with specially designed probe systems. The principle of touch-sensing mechanism can be categorized to two types, namely the touch-triggered probe and the touch-analog probe. The triggering probe only detects the moment of contact and outputs a triggered signal to lock the current position displayed by the CMM. A typical example of this type can be found in the Mitutoyo Corporation (UMAP 130). It is based on the detection principle using a vibrating element whose amplitude is reduced on contact with a surface (Masuzawa, 1993). This effect is independent of the approach direction, so true 3D measurements are possible. The touch-analog type is designed with moveable suspension plate or frame in the mechanism and the motion can be detected by built-in sensors. A variety of such probe systems have been designed, such as the silicon-

based (Haitjema, 2001), flexture structure-based (Kung, 2007), and NPL probe (Peggs, 1999). More details can be found in (Weckenmann, 2006).

The probing ball has to be made as small as possible. Most of the above-mentioned probes produce the stylus by gluing a commercially available micro sphere onto a metal stem. Such a process will inevitably incur the offset error of the ball to the center of the stylus. Even though many probe systems announce the measuring uncertainty from 50nm to 20nm, the technique of probe radius compensation has never been mentioned.

A new analog contact probe is designed and a ptototype is made in this study. This contact probe is composed of a monolithic fiber stylus with a ball tip, a floating plate and focus sensors. The ball tip is fabricated using optical fiber with melting and solidification processes, which can ensure the required diameter, roundness and center offset to the tolerance less than 1μm. The design principle and calibration of the innovative probe are explained in the follwing sections.

3.2 Fabrication of stylus

A technique of fabricating monolithic probe stylus with melting and solidification processes of a thin glass fiber to form a micro-sphere tip has been developed by the authors (Fan, 2006). The single mode (SM) glass fiber with 125μm diameter is selected to manufacture the ball tip. Glass fiber has sufficient mechanical strength to perform contact measurements. It can be easily fused within an appropriate heating field. The fiber tip absorbs the arc discharging power and melts instantaneously. The is the principle of fiber splicing, as shown in Fig. 8. Due to the surface tension, the melting part of the fiber starts to form a spherical tip gradually during solidification. The FITEL S199S model single mode fiber fusion splicer is the basic apparatus employed in this experiment, as shown in Fig. 9. The principle of the fiber splicerA fabricated fiber is mounted onto a V-groove fiber holder and the fiber fixture is precisely positioned by an XY stage. With proper selection of the process parameters in the splicer the end face of the glass fiber can be melted and then solidified to a micro-sphere due to the surface tension phenomenon. However, the sphere will droop due to the gravity effect. Therefroe, a rotary stage is added to keep rotating the melt fiber while it is solidified in order to compensate the gravity effect.

The quality of the fiber probe can be controlled by process four parameters, including arc power, fusing times, cleaning arc power offset and cleaning time. The optimal fabricating parameters are obtained for getting precise probe diameter, best probe roundness and smallest center offset using the Taguchi method (Fan, 2008). The image of one of the probes viewed at four angular positions is shown in Fig. 10. The corresponding measured results are summarized in Table. 1. All errors can be controlled to within 1 μm.

In practice, the fiber stylus may produce elastic deformation under contact force, which will yield complex mechanics. The stylus has to be hardened. One solution is to insert the fiber stem into an medical injection needle so that the stem can be very rigid. Besides, the tip ball is coated with a chromatic film by deposition process with rotating technique so that the ball can resist the wear.
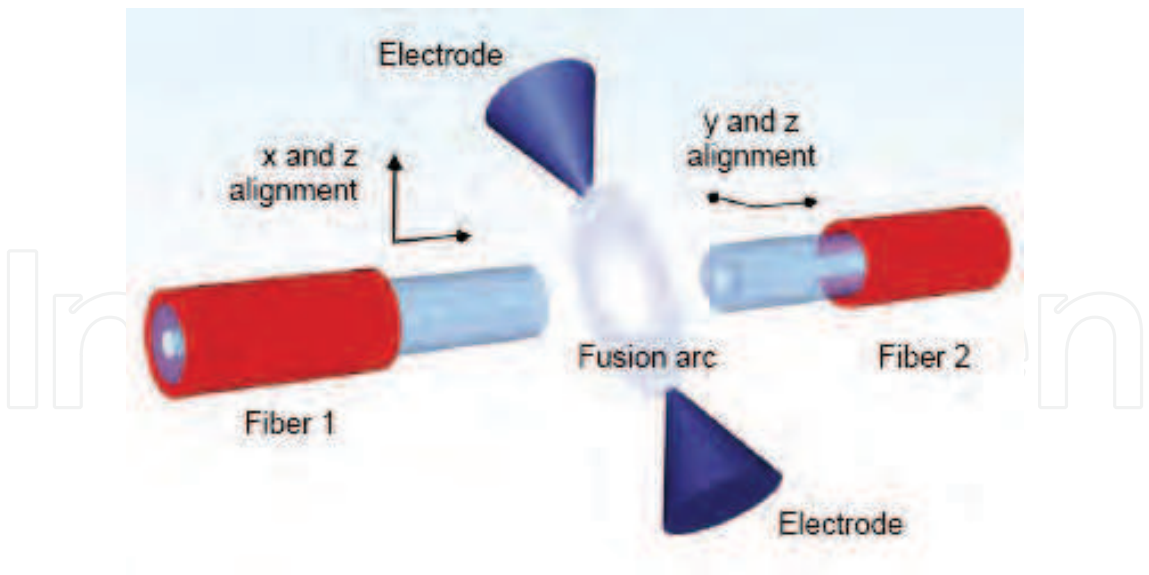
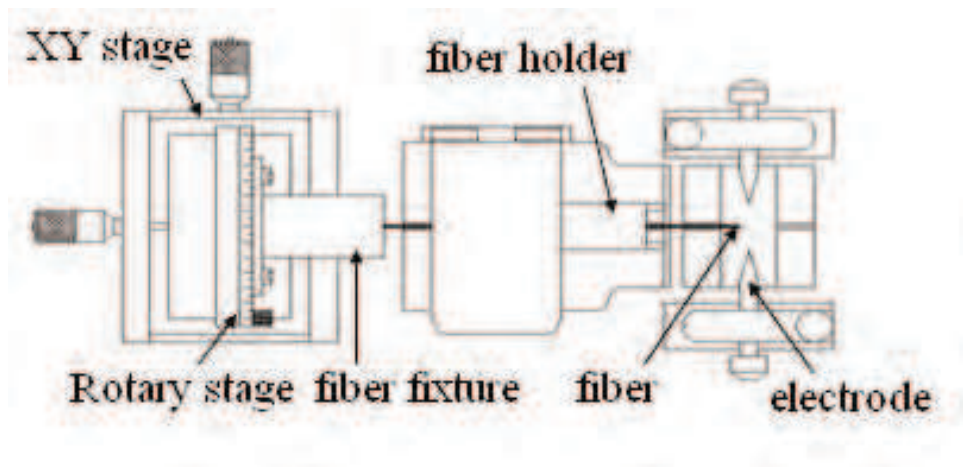Fig. 8. Principle of fiber fusion splicing

Fig. 9. Experiment setup for fiber tip fabricating

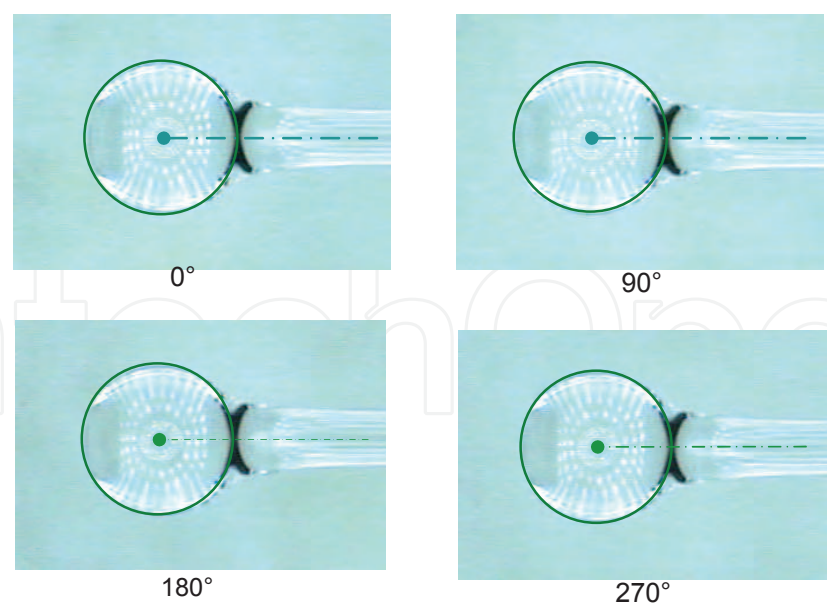| Angle of view	0°	90°	180°	270°
Diameter	314.07	313.84	314.05	313.89
Roundness	0.54	0.82	0.37	0.61
Center offset	0.37	0.96	0.28	0.72

Table 1. Measurement results of the tip at four angles (in μm)

Fig. 10. Image of one fiber probe at different views

3.3 The suspension mechanism

The main task of the suspension mechanism is to give the probe a stable rest position and a tilt angle relative to the contact force in three orthogonal directions. Fig. 11 shows the proposed mechanism of a contact probe. The glass fiber probe stylus is fixed to a floating plate which is suspended by four evenly distributed wires connected to the probe case. The contact force will cause tilt motion of the plate and four wires will perform elastic deformation. Four mirrors mounted onto respective extended arms will amplify the up/down displacement at each mirror position. As shown in Fig. 12, these displacements can be detected by four corresponding focus probes developed in this work, as described in section 2.1. The dimension of the mechanism can be simulated by finite element method to obtain optimum design. Because of the symmetrical geometry, the force-motion sensitivity should be symmetrical in X-Y plane.
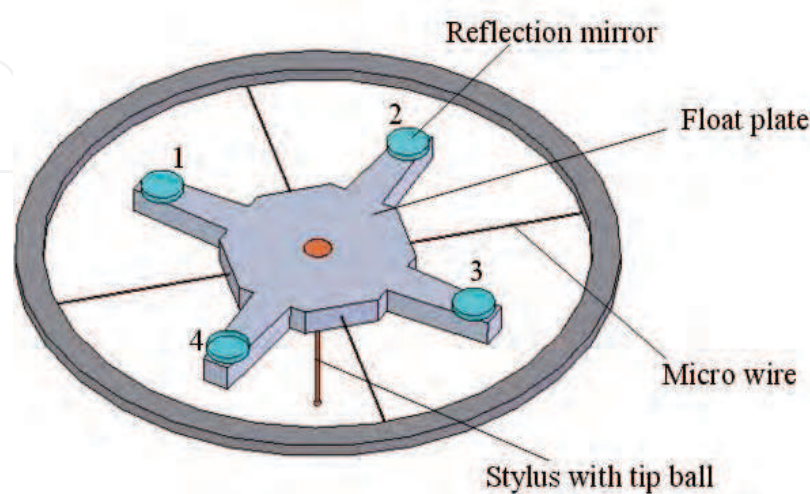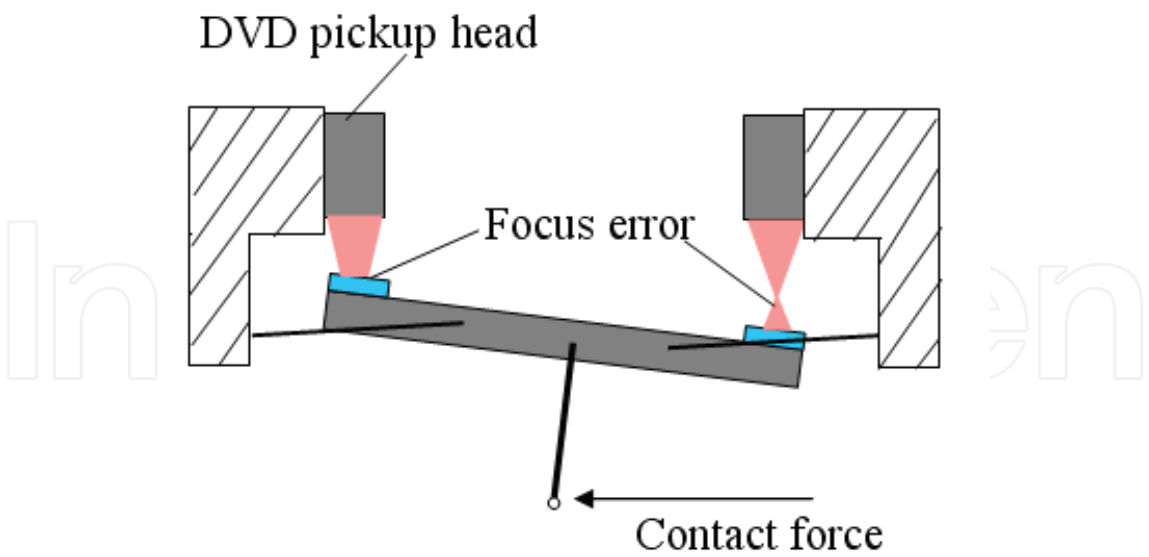

Fig. 11. The suspension mechanism of the contact probe

Fig. 12. Structure and motion of a touch-analog probe

3.4 Sensor integration

The sensor used in this touch analog probe is based on the laser focus probe which is reconfigured from the DVD pickup head. Being a mass produced device, the pickup head is cheap and very accurate. The laser focus probe adopts astigmatic principle, as described in section 2.1. The displacement of the reflection mirror will output a focus error signal (FES) from the embedded quadrant photodetector. This FES performs extremely linear curve in the focusing range with a resolution to 1nm. The pickup head is reconfigured with a special design, as shown in Fig. 13. Fig. 14 shows the integration of four sensors in the probe head without the floating mechanism. Since the FES signal is analog to the tip displacement after contact, the combination of four FES signals can reveal the angle and displacement of the probe ball, being a contact scanning mode.
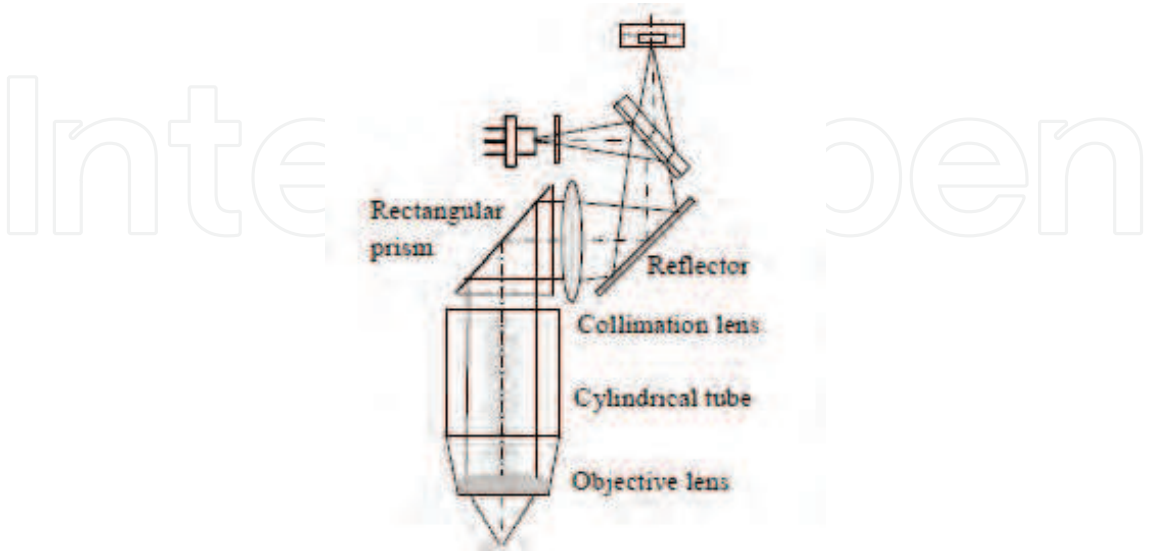

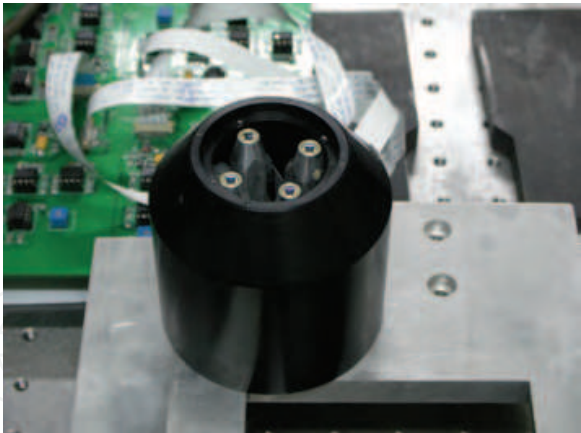Fig. 13. Reconfigured DVD pick-up head

Fig. 14. Photo of the probe head

3.5 Calibration of the contact probe
 (1) Contact force calibration
A highly sensitive force measurement appratus has been designed and its schematic diagram is shown in Fig. 15a. A thin leaf plate is built in the base. When a small force is applied to its end, a bending angle can be detected by an angular sensor, which is made from a DVD pickup head based on the principle of autocillimator, as shown in Fig. 15b. This force sensor has been calibrated by some known weights and its linear range of force to voltage is appraent in the range of 1mN. In the experiment, a microscope CCD is used to control the velocity of probe contact, as shown in Fig. 16a. Changing the contact point of the probe ball to its normal direction, the corresponding contact force can be measured. Calibrated results are shown in Fig. 16b from which it can be seen that the forces are nearly balanced in horizontal XY plane. The average contact force calibrated is 109μN.
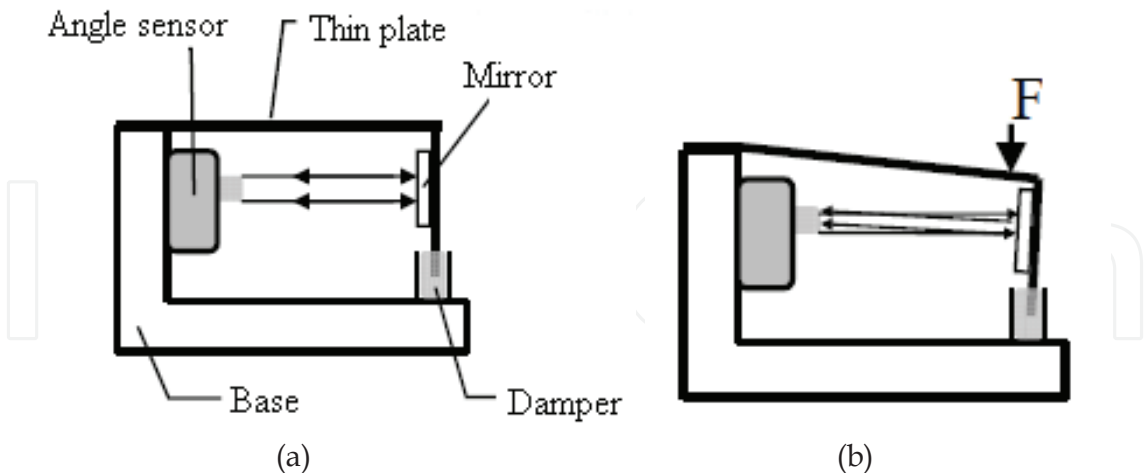

(a)   (b)

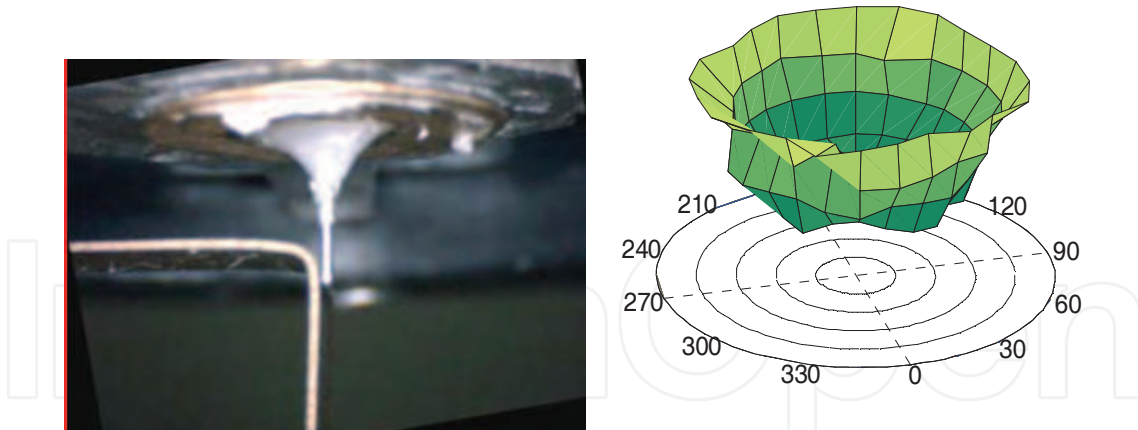Fig. 15. Force sensor, (a) Schematic diagram, (b) Under load

Fig. 16. Contact force calibration, (a) experimental photo, (b) 3D force plot

(2) Contact displacement calibration

The moments of touch, trigger and analog motion of the probe relative to the measured part are different, as shown in Fig. 17. Before contact, the probe is at rest with no output signals from the focus sensors. The trigger point is at the time the sensors detect the tilt motion of the floating plate. The distance between the touch and the trigger points is called the pretravel distance, and distance after the trigger point is called the overtravel or the analog distance. Within the analog range, the sensor output is linear to the displacement. The trigger point is the intersection of two linear lines. The actual displacement can be calibrated by a linear stage with a laser interferometer as the feedback sensor. Repeating this program for ten times, the standard deviation is calculated and the result is 8.9nm.

For the directional tests of contact, 24 directions with 15 degrees separation on the horizontal plane are tested. Fig. 18 shows quite symmetrical result with only 20nm variation at trigger points. Compared to normal 3-point support CMM probe that will appear 3 lobes characteristics, this 4-point support probe exhibits insignificant lobing effect, being insensitive to the contact direction. This contact probe can be equipped to a micro-CMM, which is being developed by the author's group.

4. Conclusion

This chapter addresses the needs of probe technology for micro/nano measurements of meso/micro parts. Three kinds of probes have been developed, namely the focus probe, the confocal microscope, and the contact probe. The focus probe is for pint-to-point measurement of 3D profile featuring high resolution (1nm) and high accuracy (a few nanometers) and insensitive to material property by normalization technique. The confocal microscope using fiber image bundle technique can measure area profile large vertical range but the accuracy is limited to 0.1μm at the present. The contact probe can measure side walls with minimum contact force of 50μN. It has to be equipped into a high precision micro-CMM to achieve 3D measurement with either touch trigger mode or touch analog mode. For different measurement requirements we shall select proper probes.
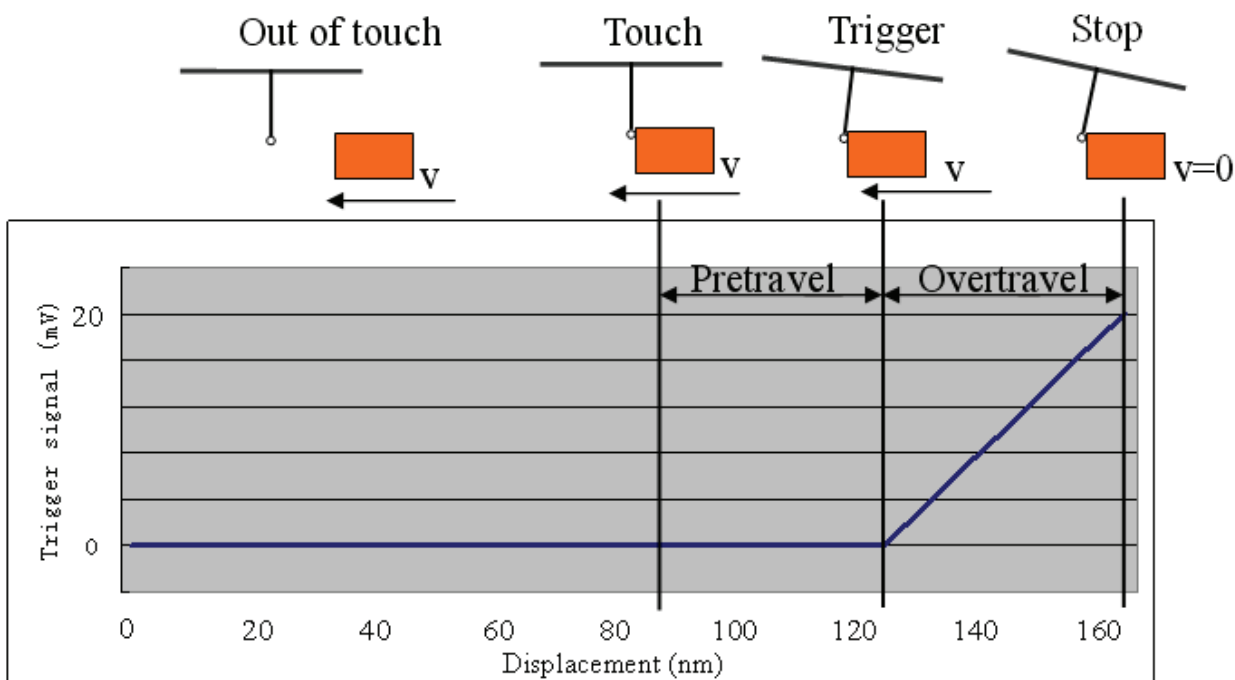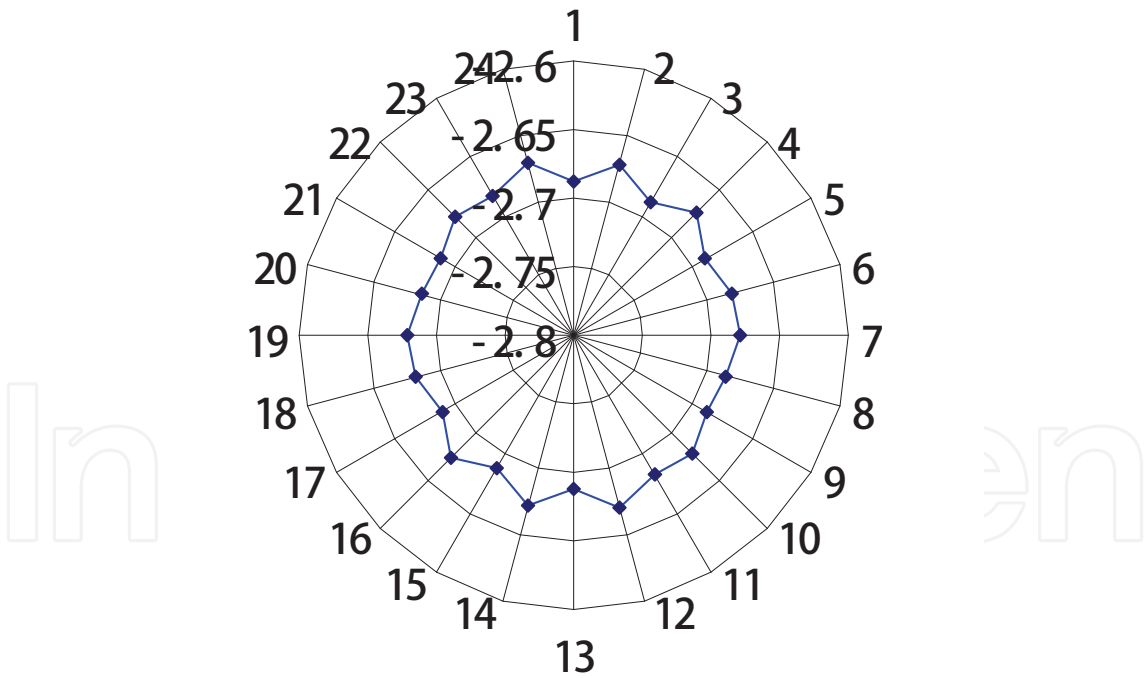
Fig. 17. The output signals before and after contact

Fig. 18. Probe response to different contact angles

5. References

Minsky, M. (1961). Microscopy apparatus, USA patent 3013467.

Masuzawa, T.; Hamasaki, Y. & Fujino, T. (1993). Vibroscanning method for nondestructive measurement of small holes, *Ann. CIRP*, Vol. 42**,** 589–92.

Jordany, H.; Wegner, M. & Tiziani, H. (1998). Highly accurate non-contact characterization of engineering surfaces using confocal microscopy, *Measurement Science and Technology*, Vol. 9, 1142–1151.

Peggs, G. N., Lewis, A.J. (1999). Design for a compact high-accuracy CMM, *Annals CIRP*, Vol. 48, 417-420.

Fan, K. C.; Lin, C. Y. & Shyu, L. H. (2000). Development of a Low-cost Focusing Probe for Profile Measurement, *Measurement Science and Technology*, Vol. 11, No. 1, 1-7.

Bitte, F.; Dussler, G. & Pfeifer, T. (2001). 3D micro-inspection goes DMD, *Optics and Lasers in Engineering*, Vol. 36, 155-167.

Haitjema, H.; Pril, W.O. & Schellekens, P. (2001). Development of a Silicon-based Nanoprobe System for 3-D Measurements, *Annals CIRP*, Vol. 50, 365-368.

Mastylo, R.; Manske, E. & Jäger, G. (2004). Development of a focus sensor and its integration into the nanopositioning and nonomeasuring machine, *TM-Technisches Messen*, Vol. 71, No. 11, 596-602.

Ni, J. (2004). Future direction of micro/meso-scale manufacturing, invited speech, Proceedings of the 6th ICFDM'2004, Xi'an, China, June 21-23.

Sawada, K. (2004), Explanation of ultra precision (nano) machine tools, keynote speech, Proceedings *of the 1st ICPT*, Hamamatsu, Japan, June 9-11.

Fan, K. C.; Fei, Y. T.; Yu, X. F.; Chen, Y. J.; Wang, W. L.; Chen, F. & Liu, Y. S. (2006) Development of a low cost micro-CMM for 3D micro/nano measurements, *Measurement Science and Technology*, Vol. 17, 524-532.

Fan, K.C.; Hsu, H.Y.; Hung, P.Y.& Wang, W.L. (2006). Experimental study of fabricating a micro ball tip on the optical fiber, *J. of Optics A: Pure and Applied Optics*, Vol. 8, 782-787.

Weckenmann, A.; Peggs, G. & Hoffmann, J. (2006). Probing systems for dimensional micro- and nano-metrology, *Measurement Science and Technology*, Vol. 17, 504-509.

Fan, K.C., Chen, Y.J. and Wang, W.L. (2007) Probe technologies for micro/nano measurement, Invited paper, *Proceedings of IEEE-Nano*, 989-993, August 2-5, Hong Kong.

Fan, K.C.; Jager, G.; Chen, Y. J. & Mastylo, R. (2007) Development of a non-contact optical focus probe with nanometer accuracy, *Proceedings of the 7th EUSPEN conference*, 278-281, May 20-24, Bremen, Germany.

Küng, A.; Meli, F. & Thalmann, R. (2007). Ultraprecision micro-CMM using a low force 3D touch probe, *Measurement Science and Technology*, Vol. 18, 319-327.

Sasaki, T.; Ishida, T.; Teramoto, K.; Kawai, T. & Takeuchi, Y. (2007), Ultraprecision micromilling of a small 3-D parts with complicated shape, *Proceedings of the 7th EUSPEN conference,* 388-391, May 20-24, Bremen, Germany.

Fan, K.C.; Wang, W.L. & Chiou, H.S. (2008). Fabrication optimization of a micro-spherical fiber probe with the Taguchi method, *J of Micromechanics and Microengineering*, Vol. 18, 0150111, 1-8.

Cutting Edge Nanotechnology

Edited by Dragica Vasileska

The main purpose of this book is to describe important issues in various types of devices ranging from conventional transistors (opening chapters of the book) to molecular electronic devices whose fabrication and operation is discussed in the last few chapters of the book. As such, this book can serve as a guide for identifications of important areas of research in micro, nano and molecular electronics. We deeply acknowledge valuable contributions that each of the authors made in writing these excellent chapters.

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