Development of a Computer-Aided Inspection System for Nano-Materials Processing

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ABSTRACT

Spraying and coating technologies are gradually being emphasized as a promising method for fabrication of thin film. Greater comprehension about the properties of thin film in qualitative manner is intensively required to satisfy the needs of production process. Therefore, ensuring thin film quality through an on-line, real-time, monitoring system has been and remains a major challenge and goal. The objective of this paper is to develop a monitoring system to handle the automated in-process inspection of thin film. The developed inspection system is based on the use of an ultrafast Ti:Sapphire laser with pulse duration of less than 100 femtosecond. A differential time-domain spectroscopy is employed to determine the refractive index. The capability of measuring the dielectric constant is experimentally demonstrated. The results indicate that the system is able to simultaneously determine the index of refraction and the dielectric constant for thin film. Also, it has sufficient sensitivity to perform these measurements on thin film.

Keywords: computer-aided inspection, refractive index, absorption coefficient.
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1 INTRODUCTION

Nano-materials already exhibit many property advantages over conventional coarse materials. They are attractive for various functional performance applications. Examples include: wear resistance surfaces, thermal resistance, anti-electrostatic, anti-EMI, infrared absorption, anti-soiling, corrosion resistance, anti-bacteria, abrasion resistance, photo catalytic functions, gas-sensitive materials and more. Surface and coating technologies are widely used to produce a thin film to achieve functionality using nanomaterials.

It has been shown that bulk materials with grain sizes in the nanometer range possess an abrasion resistance more than double that of the most resistant conventional coarse-grained materials [1-3]. Atmospheric plasma spraying (APS) has been used to produce nanostructured oxide coatings for improved wear resistance [4-5]. Ultrasonic spray methods have been used to successfully deposit highly nano-crystalline thin films onto alumina substrates to fabricate gas-sensing materials [6-7]. In comparison with conventional sintered bulk gas sensors, thin film gas-sensing materials have good sensitivity, an optimum operating temperature and selectivity. In addition, sensors based on thin films gas-sensing materials are employed to detect toxic and combustible gas.

Considerable research studies have been carried out to examine properties of nanomaterials. The mechanical properties of nanomaterials can have important applications in terms of the development of new products. Scanning probe microscopy (STM) has proven to be a useful tool in manipulating and characterizing the properties of individual nanostructures. Transmission electron microscopy (TEM), on the other hand, has been applied when characterizing the internal structures of nanomaterials [8-10]. Moreover, greater comprehension about the properties of thin film in qualitative manner is intensely required to satisfy the needs of the production process. The major quantitative items include the flatness of the surface, adhesion between film and substrate, dielectric constant or refractive index, and the dispersion information of such film materials. Chen and his colleagues have already deeply studied the flatness and adhesion of thin film [11]. Furthermore, it is crucial to know the dielectric constant or refractive index and its dispersion information in regards to thin film materials.

T-ray, which is electromagnetic radiation in a frequency interval from 0.1 to 10 THz and which occupies a large portion of the electromagnetic spectrum between the infrared and microwave bands, offers innovative imaging and sensing technologies that can provide information not currently available through conventional microwave and X-ray techniques [12-13]. Due to the relatively long wavelength, the conventional time-domain spectroscopy does not provide adequate sensitivity to the measurement of thin film. In this paper, we propose a differential time-domain spectroscopy to determine the refractive index. The capability of measuring the dielectric constant is experimentally demonstrated.

2 COMPUTER-AIDED INSPECTION SYSTEM

The developed inspection system is based on the use of an ultrafast Ti:Sapphire laser with pulse duration of less than 100 femtosecond. A probing beam is generated by a set of electro-optical devices. The system is controlled by a computer through a Labview supported program. Unlike common optical spectroscopes, which only measure the intensity of light at specific frequencies, the developed time-domain spectroscopic system directly measures the temporal electric field. Fourier transformation of this time-domain data gives the amplitude and phase of the T-ray wave pulse, therefore providing both the real and imaginary parts of the dielectric constant. This allows for precise measurements of the refractive index and the absorption coefficient of samples.

In this system, a large-aperture photoconductive antenna and electro-optic crystal is used to generate a T-ray wave, and an electro-optic crystal ZnTe is used to detect the T-ray wave. Figure 1 shows a schematic diagram of the developed system. This system measures the far-infrared spectroscopy. The mode-locked femtosecond laser beam is aligned through two irises; it is then separated into two pulses by a resolution beam splitter, namely, a pumping beam and probing beam. A half-wave plate is used to change the intensity ratio of the pumping and probing beam. The pumping pulse illuminates the T-ray emitter to generate a T-ray pulse in a forward direction. The emitter is a photoconductive antenna on a semi-insulating GaAs wafer. A high DC voltage is applied across the electrodes of the antenna to accelerate the photoelectrons generated by the pumping beam. A transient photocurrent generates free-space radiation. A gold-coated parabolic mirror collimates the T-ray radiation, while a second one focuses the T-ray beam onto the T-ray sensor. A pellicle is placed after the second parabolic mirror to steer the probing beam. This allows the probing beam to travel collinearly with the T-ray beam inside of the EO crystal, where the probing beam is modulated by the electrical field of T-ray radiation via the electro-optic effect.

A quarter-wave plate, a Wollaston prism and a pair of photodiodes are assembled for the balanced detection of the probing beam. The time delay between the pumping and probing pulses is controlled by a motorized translation stage. The temporal waveform of the T-ray pulse is obtained by measuring the photocurrent from the detector versus the time delay. The frequency spectrum of the T-ray signal is obtained by the fast Fourier transfer method (FFT). The system is controlled by a computer through a Labview supported program. The measured T-ray waveform and its Fourier transform spectrum are shown in Figure 2. In order to incorporate this system into CIM, an interface for remote control through the GPIB is created. Figure 3 exhibits the remote control interface for the operation of this measurement system.

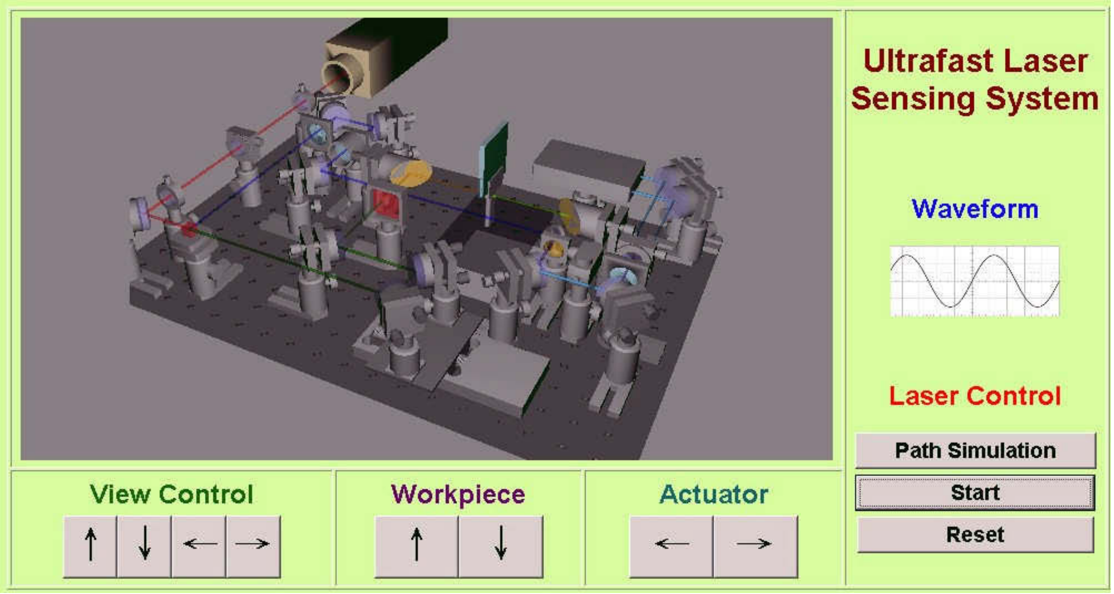
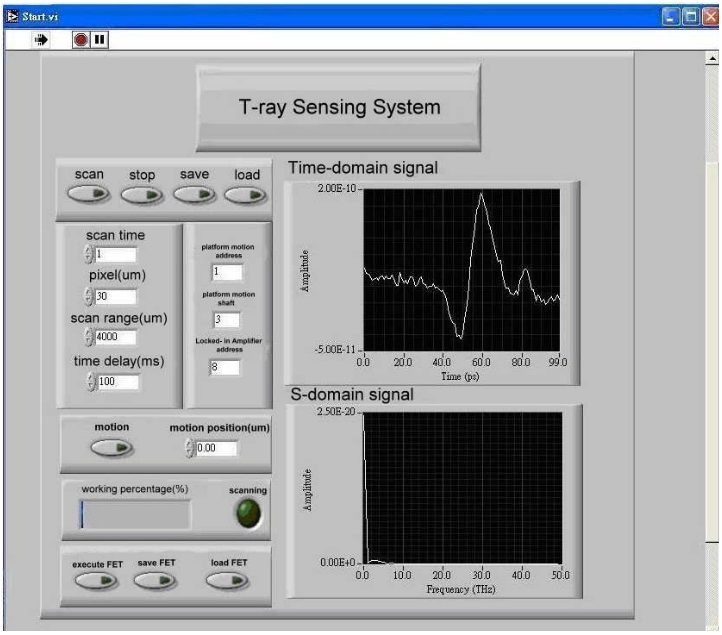
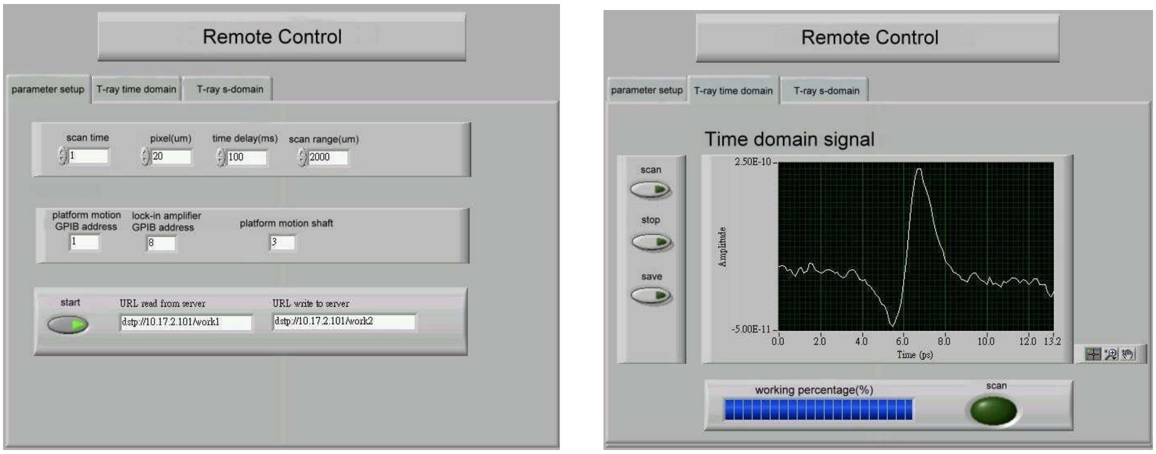


Fig. 1: Computer-aided inspection system for nano-materials.



scan time 1
pixel(um) 30
scan range(um) 4000
time delay(ms) 100
platform motion address 1
platform motion shaft 3
Locked- in Amplifier address 8
motion position(um) 0.00

Fig. 2: Sensing system.



scan time: 1
pixel(um): 20
time delay(ms): 100
scan range(um): 2000
platform motion GPIB address: 1
lock-in amplifier GPIB address: 8
platform motion shaft: 3
URL read from server: dstp://10.17.2.101/work1
URL write to server: dstp://10.17.2.101/work2

Fig. 3: Remote control interface.

3 INDUSTRY APPLICATION

The dielectric properties of film materials are an essential issue for the fabrication of a high performance product. In this system, the phase change of the T-ray waveform is measured when the thin film is inserted into the T-ray beam. The frequency-domain information is obtained by comparing the Fourier transforms of the T-ray waveforms measured with and without the thin film. The real and imaginary values of the refractive index, n and k respectively, can be obtained from the following equations: $n(v)=1+\frac{c}{2\pi vd}\left[\phi_1(v)-\phi_2(v)\right]$; $k(v)=-\frac{c}{2\pi vd}\ln\left[\frac{E_1(v)}{E_2(v)}\right]$

where φ_i and E_i are the phase and the amplitude of the T-ray waveform respectively, d is the thickness of the film under measurement and the subscripts 1 and 2 stand for the measurements with film and without film. Then, the dielectric constant (ε) of the thin film can be computed by the equation:

$$\varepsilon=\left(n-ik\right)^2$$

The real and imaginary parts of the dielectric properties in the frequency domain can be extracted through a Fourier transformation from measured T-ray amplitudes and phases in time-domain. Thus, experiments were conducted in time domain. The intensity of the electromagnetic radiation (T-ray) can be calculated by: $I=I_o\left(1-R\right)^2\exp^{(-aXL)}$

where I is the intensity of the T-ray after the penetrating sample, I0 is the intensity of the T-ray before penetrating sample, R is the surface refractive coefficient of the sample, a is the surface absorption coefficient of the sample, and L is the thickness of the sample.

Figure 4 shows the response of the T-ray to collagen powder. A specific spectrum of the T-ray appears when the powder is inserted into measuring system. This gives us a chance to enhance the function of the developed system to identify or detect the types of material automatically. Figure 5 presents the phenomena occurring when the intensity of the T-ray decreases with an increase in thickness. The peak amplitude is in 3.3ps without the test sample. The spectrum slightly shifted about 0.9ps upon the addition of one polyester plastic sample. The thickness of each polyester plastic sample can be computed as 0.027mm (0.9psX3X108m/s), which is as desired.

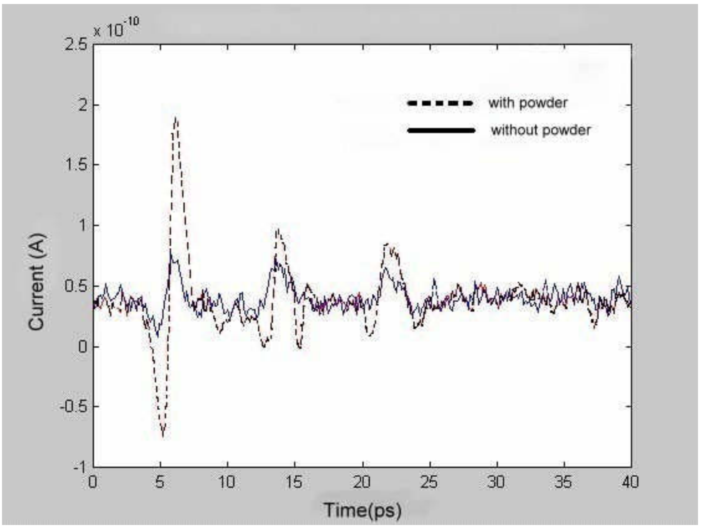


Fig.4: T-ray of collagen powder.

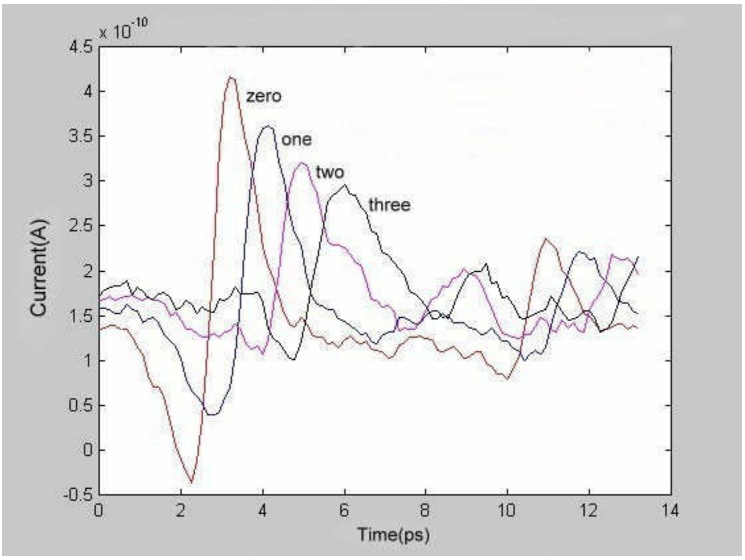


Fig. 5: T-ray of polyester plastic material.

4 CONCLUSIONS

Thin film is gradually used to improve the functionality of existing products in current manufacturing processes. Therefore, it is important to measure and characterize the properties of thin film so as to better meet the designed requirements. In this study, an inspection system is developed using an ultrafast Ti:Sapphire laser. A series of experiments are conducted to demonstrate the usefulness of the concepts and approaches proposed in this research. This system is able to offer sub-millimeter resolution. In addition to measuring the dielectric constant and the refractive index in real time, this system can be expanded to identify or detect the types of material automatically.

5 ACKNOWLEDGEMENTS

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