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DEVELOPMENT OF THE ULTRA HIGH-RESOLUTION ACOUSTIC MICROSCOPY SYSTEM FOR PRECISION DIAGNOSIS ON HIDDEN DAMAGE OF MICRO/NANO STRUCTURE

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ABSTRACT

A method for evaluating the thin film properties, destructive testing such as scanning electron microscope was generally used. Since the electron microscope has a limit to surface-based analysis, it requires nondestructive evaluation techniques to analyze the interface as well as the surface. The acoustic microscopy system (AMS) has been used to non-destructively detect hidden damages and evaluate material properties in micro/nano structures. In recent times, the development of high-frequency acoustic microscopy system has been required as the thicknesses of thin films have gradually decreased. In particular, transducer-lens and pulser/receiver are the major components affecting the performance of an AMS. In this study, a high-resolution prototype-AMS was developed to analyze the characteristics of thin films. Piezoelectric transducers were deposited with various thicknesses of the ZnO thin films on a sapphire lens using RF sputtering. The prototype device also had an integrated pulser/receiver and a data acquisition system. Based on the results, the developed high-resolution AMS can be used for diagnosis/inspection of micro/nano structural damages in thin films.

Keywords: *acoustic microscopy system(AMS),*

1. INTRODUCTION

Micro and nano thin films are used in various fields, ranging from optical coating to semiconductors. As these thin films become more highly integrated in recent years, techniques are needed for assessing the characteristics of not only the surface but also the surface layer and interface. Transmission electron microscopy (TEM) and scanning electron microscopy (SEM) were representative techniques used to analyze the surface and surface layer of thin films. Scanning tunneling microscopy (STM) and atomic force microscopy (AFM) have been used to analyze surface characteristics. In addition, destructive techniques such as scratch testing have been used to assess thin film properties such as interface characteristics and bonding strength [1-4]. In this regard, most existing analytical techniques can only be operated in ultra-high vacuum conditions, require extensive time to prepare test specimens, or may damage the material through destructive techniques. This makes it impossible to maintain the thin film's functions after experimentation. Accordingly, many non-destructive techniques have been applied to analyze thin film characteristics. Among them, studies have employed the ultrasonic scanning acoustic microscope (SAM) technique to evaluate surface and internal images and material characteristics.

The SAM technique focuses the ultrasonic waves generated from the piezoelectric element on a spherical acoustic lens to obtain high-resolution images of the surface and interior of the material. Moreover, by analyzing the acoustic signals obtained through mutual interference between surface waves generated in micro-areas on the surface and directly reflected longitudinal wave signals, this technique can measure the velocity of the leaked surface waves and precisely measure the material's mechanical properties nondestructively and without contact. However, the frequency of the existing ultrasonic microscope has a resolution limit when evaluating thin films with a micro or nano structure. In this study designs and fabricates an ultrasonic microscope system and evaluates its performance in assessing the characteristics of micro and nanostructure thin films.

2. INTEGRATION OF AMS

The structure of the acoustic microscope is divided into three types: an ultrasonic lens, a pulse generator and receiver unit for receiving and transmitting electric signals, and an image processing unit. The acoustic microscope identifies internal defects by imaging the surface or internal shape of a material with ultrasonic waves. The images of the internal microstructure are represented as the sound reflected due to changes in impedance in the sample. When ultrasonic waves irradiate on the

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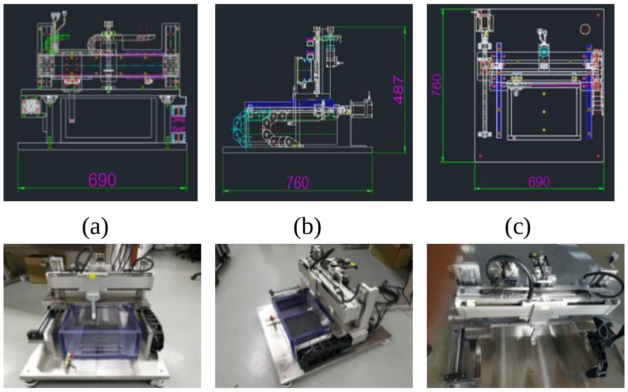
sample, some of the waves penetrate through the sample while the rest are reflected. The signal reflected from the specimen is determined through the elastic modulus of the material and is received by the transducer. In this signal, the axial force of the transducer is called the V(z) curve, a function of the distance. By analyzing this, the surface and internal shape of the shape can be imaged, while the properties of the material (density, acoustic velocity, acoustic attenuation coefficient) can be determined through frequency conversion.

2.1 Motion Control Part

In order to develop a high resolution acoustic microscope able to precisely diagnose hidden damage to the micro/nano structure, we designed and fabricated a mechanical part and driving part. It is necessary to precisely transfer and control the three axes in the unit on a microscale level in the driving part. Figure 1 shows an image of the designed mechanical part and driving part. The fabricated driving part consists of a control unit (PC and control software), an ultrasonic unit (Pulser/Receiver), and a water tank in one system. The mechanical part comprises three axis of X, Y, and Z. The maximum scan range is 300 mm x 300 mm.



(a) (b) (c)

(d) (e) (f)

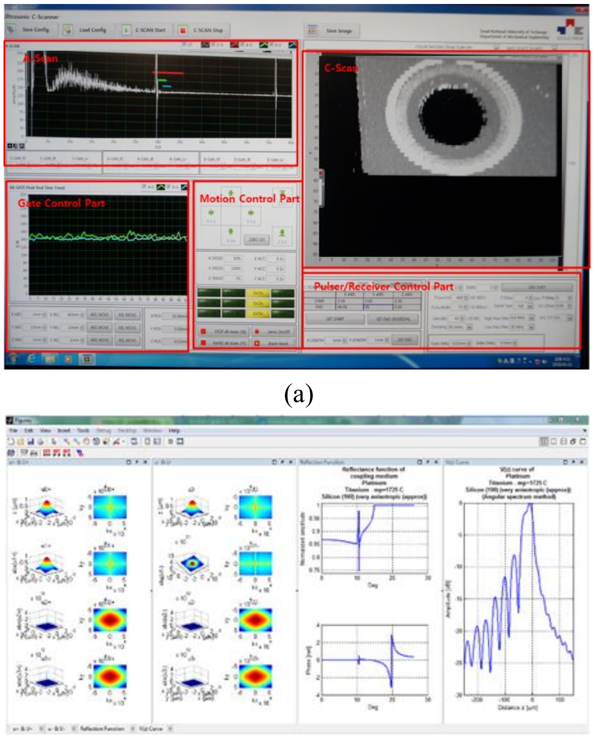
FIGURE 1: Front view, side view and top view of manufactured 3-axis control device. (a) to (c) design images and (d) to (f) produced images

2.2 Design and Fabrication of Activation Module

For the high-resolution ultrasonic microscope system developed in this study, it is essential to develop a pulser/receiver capable of high frequency bands. The V(z) curve technique, a major feature of the SAM method, is used to measure the sound velocity at high precision in micro-areas. This enables physical property evaluation and identification of material properties such as acoustic anisotropy, twin deformation, deformed layer, thin film thickness, and residual stress of the surface layer. These V (z) curves require a pulser/receiver for which tone-burst-wave propagation is possible. The pulser/receiver usually propagates waves in the low-frequency band (1-250MHz) in the pulse-wave mode and in the high-frequency band (400GHz-1MHz) in the tone-burst-wave mode. The currently commercialized Activation Module can propagate waves of high-frequency (-500MHz) and low-frequency bands at the same time, but it does not support both the pulser and tone-burst types required in this study. Therefore, we constructed the system using a low-frequency pulser/receiver.

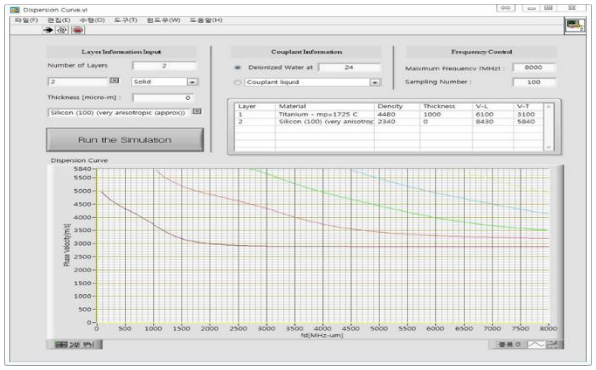
2.3 AMS Operation Software

Figure 2 shows the operation software of the developed AMS system. The signal image processing algorithm was developed by realizing C-scan images based on A-scan. However, storing all of the A-scan images may cause problems in data capacity and speed. Therefore, we made it possible to both control the amount data to be stored and select whether to store the data or not. We designed the system to realize 3D images as well as 2D B-scan and C-scan images through signal and image processing after testing. In addition, a separate evaluation program was added to evaluate the length, depth, and area of defects. Also, we developed an analytical algorithm based on acoustic modeling in micro/nano structures and developed a V(z) curve simulation program. The developed V(z) curve simulation program was coded using Matlab 2011b, and all input and output interfaces were configured using graphical user interface (GUI). It consists of simulation of the V(z) curve and surface acoustic wave velocity calculation of the simulated V(z) curve. In addition, the software is designed to calculate the velocity of the surface acoustic wave from the V(z) curve through V(z) curve simulation. And We simulated the dispersion curve of ultrasonic propagation velocity. Figure 2 (b) and (c) show the simulation results of V(z) curve dispersion diagrams, respectively.



(a)

(b)



Number of Layers 2

2 Solid

Thickness [micro-m] : 0

Silicon (100) (very anisotropic (approx))

● Deionized Water at 24

○ Couplant liquid

Maixmum Frequency [MHz] : 8000

Sampling Number : 100

Layer	Material	Density	Thickness	V-L	V-T
1	Titanium - mp=1725 C	4480	1000	6100	3100
2	Silicon (100) (very anisotrop	2340	0	8430	5840

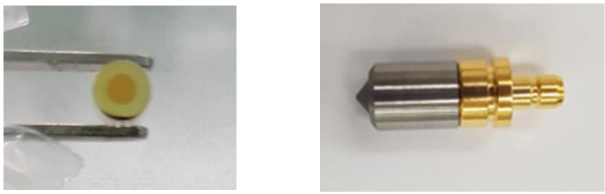
(c)

FIGURE 2: AMS system operation software. (a) signal image processing data, (b) V(z) simulation data and (c) dispersion diagrams simulation

3. FABRICATION OF ACOUSTIC SENSOR

3.1 ZnO piezoelectric Sensor

In order to fabricate a high-frequency sensor, piezoelectric material should be used to fabricate the piezoelectric thin film. Particularly, among piezoelectric materials, ZnO (zinc oxide) is widely used for piezoelectric transducers, SAW filters, and sensors due to its high piezoelectric coupling coefficient and excellent C-axis orientation. In particular, the ZnO piezoelectric thin film displays advantageous piezoelectric properties when c-axis is grown, making it useful as a component for measuring devices or vibrators that require fine displacement. Therefore, in this study, ZnO thin films were deposited using RF-magnetron sputter. For the top and bottom electrodes, Ti and Au thin film was deposited with an electron-beam evaporator (e-beam). Finally, a wire bonding process was conducted to connect the sapphire lens that deposited the ZnO piezoelectric thin film with the designed and fabricated connector and case.



(a) (b)

FIGURE 3: Image of fabrication process of ZnO piezoelectric transducer (a) ZnO piezoelectric element and (b) Sensor casing

3.2 Performance Verification of Acoustic Sensor

We evaluated the sensor for sensitivity and resolution using existing commercialized equipment (Model: Olympus UH3). A resolution chart was created to verify the image resolution; Figure 4 shows the resolution results. Theoretically, the resolution of a sensor with 400 MHz is known to be 2.5 μm, and the smallest pattern interval that can be decomposed in the resolution chart is about 2 μm. A comparison of the performance of the developed sensor with that of the commercialized sensor shows that both sensors produced sufficiently separated and imaged patterns with an interval of approximately 2 μm.

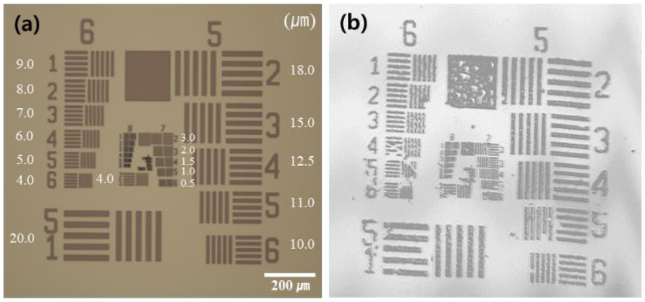


FIGURE 4: The resolution chart images (a) Optical image of resolution chart (x 100) and (b) manufactured sensor Seoultech_400MHz

4. CONCLUSION

In this study, we developed an acoustic microscope system using ultrasonic waves to evaluate the hidden damage of micro/nano structures. The ultrasonic sensor was fabricated using a ZnO piezoelectric element and obtained an image resolution similar to that of commercial sensors. However, as the amplitude of the signal is low, we will perform additional studies to improve amplitude. Currently, the commercialized Activation Module can be used for high-frequency (-500MHz) and low-frequency bands at the same time; however, as it does not support both the pulser and tone-burst types required in this study, design and fabrication of a high-frequency band pulser/receiver is in progress. Once development of the pulser/receiver is complete, we expect to optimize all the developed core elements and obtain basic technology for commercializing the GHz acoustic microscope system for assessing the damage and physical properties of micro/nano structures.

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