DEVELOPMENT OF A LASER ULTRASOUND SYSTEM FOR ELASTIC CHARACTERIZATION OF MICROSTRUCTURES

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ABSTRACT

Micro-electromechanical systems are going through a rapid development and commercialization. Industries concerned about large scale production of MEMS are looking for sensors and techniques for better controlling the processes, verifying parts conformity and durability. LTSD is developing the laser-ultrasound technique to be applied in the elastic characterization of materials and devices of interest to the electronic industries. This technique is non contact, non destructive and broadband, being ideal for determining practical parameters in the micro-scale domain, such as elastic constants, residual stress and layer thickness.

1. INTRODUCTION

Micro-electromechanical systems (MEMS) equipped with very specific mechanical, medical and optical functions are going through a rapid development and commercialization. The potential market for these MEMS is huge and it is estimated that it will reach, in the global scale, tens of billions of dollars in the coming years. These micro-systems are manufactured by means of a variety of complex processes, being most of them well-established already. Industries interested in large scale production of MEMS are looking for sensors and techniques for better controlling the processes, verifying parts conformity and durability. Since the products are small (typically below 1mm with sub-micron features) and non-invasiveness is usually an important requirement at the industrial level, optical techniques are the prime and proper choice. However, for the important and broad class of MEMS based on resonant micro-membranes (such as accelerometers, mirror arrays etc), the relevant parameters are rather mechanical (elastic constants, resonance frequency, residual stress, dimensions etc). Since ultrasound is a mechanical wave, the technique of generation and detection of ultrasound by laser, named laser-ultrasound, is ideal for non-destructive inspection of these systems [1].

The purpose of the work described herein is the development of the laser-ultrasound technique at LTSD, and its use to the non-destructive elastic characterization of materials and devices of interest to the electronic industries. LTSD focuses on the heterodyne interferometric technique [2] in order to implement the laser-ultrasound detection system. The detection system will be coupled to a PC for simultaneous data acquisition, processing and display. In the following sections, the laser-ultrasound detection system under development will be presented, and some research topics — to be carried out at LTSD with this apparatus in the near future — will be discussed. Special attention will be given to the development of techniques for elastic characterization of semiconductor wafers and micro-structures built on MEMS.

It is expected that in the course of this project a series of real problems in the production process of MEMS and IC (integrated circuits) may be identified, notably the measurement of the residual stress among different material layers. In addition, it is also expected that other related technological challenges, such as microelectronic packaging and flip chip solder joint quality inspection, to mention just a few, may be tackled with the laser-ultrasound system and inspection techniques developed at LTSD.

2. BACKGROUND ON LASER ULTRASOUND

Laser-ultrasound is a relatively novel nondestructive inspection technique that has reached some maturity and is being now used in industry. This technique employs laser beams to generate and detect ultrasound at a distance, without any contact to the specimen under investigation. A pulsed laser beam generates ultrasound through thermal expansion at low power densities (thermoelastic effect) or by vaporizing a small amount of surface material at high power densities (ablation effect). The laser-generated ultrasound is then detected upon the surface of the sample by a second laser beam coupled to an interferometer [3]. Since the ultrasound is carried by a laser beam, demodulation techniques are usually employed at the output of the interferometer in order to obtain an electrical signal proportional to the ultrasonic disturbance.

3. LASER-ULTRASOUND DETECTION SYSTEM

Figure 1 shows a sketch of the laser ultrasound detection system under development at LTSD. The setup uses a linear polarized CW He-Ne laser beam (4mW nominal power). After passing through the acousto-optic modulator (AO), two beams are generated at the output of the AO. The first laser beam (the sensor beam) is directed to a sample whose surface is under effect of ultrasonic (or vibration) motion. The sensor beam keeps the same frequency as the original laser beam. On the other hand, the second laser beam (reference beam), is diffracted and frequency-shifted. The amount of frequency shift depends on the AO design. For this particular setup, it corresponds to 40 MHz. The laser beams are properly guided, isolated from the laser source and then forced to interfere at the photodetector (PD). The result is an electric current having a DC and a 40 MHz AC components. The AC component is phase modulated by the amplitude of the ultrasonic wave at the sample's surface. Therefore, the 40 MHz AC current carries the ultrasonic wave propagating through the sample. Since the two beams have different frequencies, this interferometric technique is called heterodyne. A PLL (phase locked loop) circuit has also been designed and optimized for demodulating the ultrasonic signal.

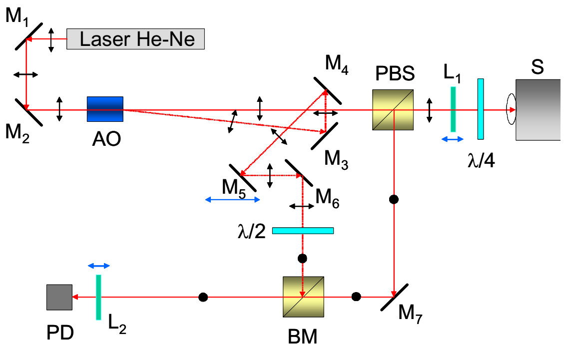

Fig. 1– Heterodyne interferometric setup of the laser-ultrasound detection system. M (mirrors); L (lenses); AO (acousto-optic modulator); PBS (polarizing beam splitter); BM (beam mixer); l/2 (half-wave plate); l/4 (quarter-wave plate); PD (photodetector);
S (sample)

A picture of the implemented laser ultrasound detection system is shown in Fig. 2. The bandwidth of the detection system is limited by the PLL circuit and ranges from 1 kHz to 37 MHz. Thus, any vibration or ultrasonic disturbance falling into this range can be used for material characterization purposes.

4. FUTURE WORK

In order to adapt the laser-ultrasound detection system to microstructures inspection routines, it is necessary to couple it to a broadband data acquisition and processing unit. Development of this unit is the next step to be undertaken and will be initiated shortly. For this task, the output of the demodulation circuit will be connected to a PC by means of an acquisition board. LabView based programs will then be developed for simultaneous data acquisition, storage, processing and visualization. Once the coupling between the laser-ultrasound detection system and the data acquisition and processing unit has been achieved, the following research topics will be started at LTSD:

i) elastic characterization of standard Silicon wafers used in the development of CI's and MEMS. By elastic characterization is understood here the in-plane and out-of-plane mapping of Young's modulus and Poisson's ratio, which are project parameters of interest to semiconductor and electronic industries [4];

ii) measurement of resonance frequencies of cantilever beams built on MEMS. Resonance frequency measurements can lead to the determination of both layer thickness and residual stress. Again, inspection tools for these parameters are of practical importance and are being investigated by several research groups [5].

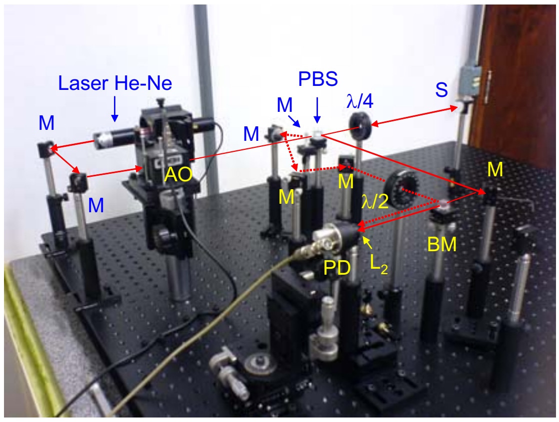

Fig. 2 – Picture of the laser-ultrasound detection system implemented at LTSD

5. CONCLUSION

A laser-ultrasound system is under development at LTSD. This apparatus will allow thorough elastic characterization of materials and microstrutures of interest to the semiconductor and electronic industries, including mechanical moduli, residual stresses and layer thicknesses determination. It is expected that in the near future LTSD will become an integrated center for electrical, optical and elastic characterization of materials and devices.

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