Interferometric Metrology for Thin and Ultra-Thin Compound Semiconductor Structures Mounted on Insulating Carriers

Wojciech Walecki, Frank Wei, Phuc Van, Kevin Lai, Tim Lee, SH Lau, and Ann Koo

Frontier Semiconductor, 1631 North 1st Street San, Jose CA 95112 fsm100@aol.com; phone: 1 408 452-8898
e-mail: wwalecki@frontiersemi.com;

Keywords: Wafer Thickness Metrology Ultra-thin Wafers, Test and Reliability

Abstract

The application of low coherence optical interferometry to measurement of compound semiconductor wafers is discussed. Proposed method allows measurements of free standing and bonded wafers, both doped and semi-insulating.

INTRODUCTION

The low coherence optical interferometry [1] has been proven to be an effective tool for characterization of thin and ultra-thin semiconductor Si wafers [2]. Purpose of this paper is to present an extension of this method to characterization of ultra-thin compound materials wafers mounted on insulating carriers.

The metrology of thin and ultra-thin compound materials wafers has been identified very early as one of the technology gaps of the industry. The most commonly employed metrologies include capacitance and air pressure techniques. These two competing technologies have been are reliable and quite accurate methods for measurement of thickness, bow, warp and related parameters in relatively thick and well conducting materials. Capacitance method however is not suitable for measuring thickness of semi-insulating and insulating materials, and very thin wafers (thinner than 100 μm). Furthermore it has relatively low spatial resolution limited by physical size of probes, and may not be suitable for direct measurement of wafers mounted on insulating materials such as glass, sapphire or plastic tape. Air pressure based sensors are able to measure insulating materials however they cannot be directly applied to wafers mounted on carriers. Both these competing technologies require access from both top and bottom sides of the wafer. For both these methods standoff distance between probes and sensor head is in the range of 0.1 – 4 mm. Very small standoff distance is making it very difficult to integrate these metrologies in in-situ or ultra-clean environments.

In this paper we present alternative technique, which does not suffer from above discussed limitations, and can be easily integrated in the production tools, and provide accurate measurement of samples while they are being processed.

METHOD OF MEASUREMENT

Experimental apparatus used in the measurement is in Figure 1, [2]. It is a fiber optic implementation of low coherence Michelson interferometer [2]. Light emitted by low coherence source A is split by means of beam-splitter 50% transmitting, and 50% reflecting beam-splitter C into two beams: one called later reference beam propagates in the reference arm of the interferometer D, second portion of the beam later called signal beam propagates in the signal arm E. The polarization of the reference beam is controlled by means of polarization controller F, and is collimated by means of lens G on mirror H. Mirror H resides on delay stage such that the length of the optical path of the reference beam is controlled by means of optical delay stage. The reference beam is reflected from the reflective element, passes again through polarization controller F is partially transmitted by beam-splitter C and directed to detector B. The signal beam E is collimated by lens I and impinges sample J. The reflected portion of the signal beam is directed by means of beam splitter C towards detector B.

The coherence length of light source A is about 30 μm, central wavelength is approximately 1.3 μm, bandwidth full width half maximum is 30 nm. The spot size of light projected on the sample has diameter approximately 60 μm.

It is worth to notice that distance between measured sample and optical sensor can be adjusted by varying length of optical fibers D and E and position of the mirror H. We have built several prototypes having standoff distances varying in range from 5 to 200 mm. This great flexibility allows easy integration in in-situ or ultra-clean environment.

The intensity of the optical beam impinging detector surface I_d is given by:

$$I_d = \tfrac{1}{2}\left(I_r + I_s\right) + \mathrm{Re}\left\{\left\langle E_r^*\left(t+\tau\right)\cdot E_s\left(t\right)\right\rangle\right\} \qquad (1)$$

where I_s and I_r are signal and reference beam combined by beam-splitter C shown in Figure 1, τ is delay equal to difference of the optical paths of the signal and reference beams, t is time, E_r and E_s are electric fields of reference and signal beams respectively, and angle $\langle ... \rangle$ bracket means averaging over t .

When optical paths of the signal and reference beams differ by much more than coherence length of the source the intensity detected by detector is simply equal to the first τ - independent term in the Equation (1), however when the path of the reference and signal beams are different within the coherence length than the second term becomes comparable to the first term. This phenomenon is well known and was applied in past for distance ranging since the optical delay time is related to difference in length Δl between the reference and signal beams by simple formula:

$$\tau = 2 \cdot n \cdot \Delta l \qquad (2)$$

where n is refractive index of the medium. The Equation (2) implicitly assumes that medium is non-dispersive within

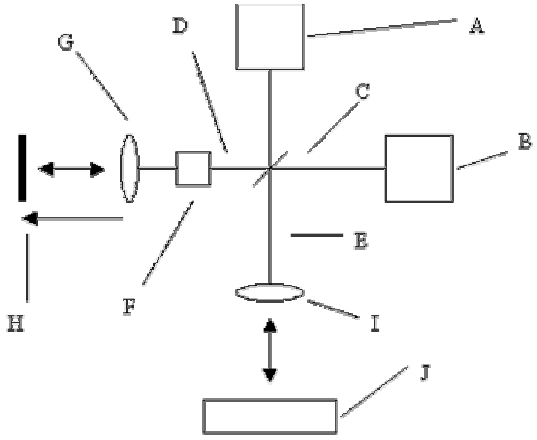

Figure 1: Apparatus used in described experiment comprising of A low coherence source, broad bandwidth infrared source A, detector B, beam-splitter C reference, arm D and signal arm E. Reference arm D comprises of polarization controller F, collimating lens G, and mirror mounted on delay stage H. Signal arm E comprises collimating lens I and sample J.

the bandwidth of the light source, which is quite good approximation in the most commonly encountered cases.

RESULTS

It is straightforward to extend our technique to measurement of multi-layered optical materials [2]. In our previous paper [2] we have discussed use of the scattering matrix formalism for analysis of structure comprising of arbitrary number of transparent layers. In this paper we would like to focus our attention on the case when said layers are much thicker than

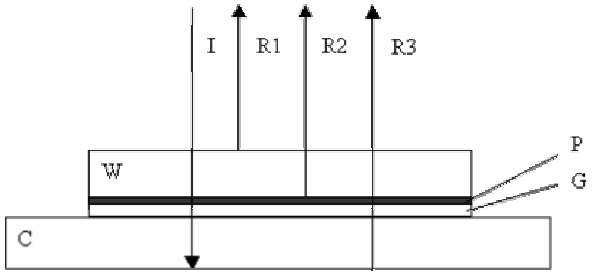

Figure 2: Compound semiconductor wafer W mounted on insulating carrier C by means of wafer gripper G deposited on pattern P carrier C interface. Low coherence beam I is impinging top surface of the wafer W, is partially transparent pattern P, wafer gripper G.

the coherence length of light, as it is in case of sample mounted on transparent sapphire carrier shown in Figure 2.

Interferogram of light reflected from this structure is presented in Figure 3 below. The interferogram reveals three strong features: R1, R2, and R3. Features R1 and R2 are attributed to reflection from top and bottom surface of GaAs wafer, while feature R3 corresponds to reflection from the bottom surface of sapphire carrier C defined in Figure 1.

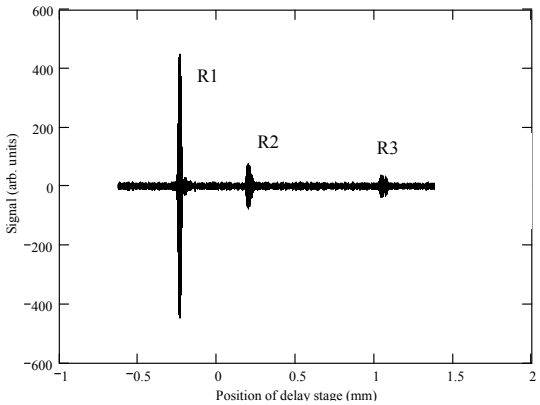

Figure 3: Interferogram of the low coherence light reflected from sample. Features R1, R2, and R3 correspond to reflections discussed in Figure 2.

Feature R3 is broadened and partially split due to superposition of birefringence in sapphire substrate C, and Fabry-Perot interference in the wafer gripper G. Closer inspection of the emission corresponding R2 peak reveals asymmetrical shape and beatings, which result from Fabry-Perot interference in the wafer gripper having thickness significantly smaller than coherence length of radiation used in the experiment. Measured GaAs wafer thickness was 118.5 μm. Typical reproducibility of the measurement on patterned GaAs samples is better than 0.4 μm (1 sigma) measurement takes about 0.3 sec. Higher reproducibility can be achieved by averaging results of many measurements. The absolute accuracy is a function of accuracy of the value of refractive index used for calculation of the optical delay between features R1 and R2, and typically is 0.7 μm or better.

It is worth to notice that presented here technology can be coupled with spectral interferometry to examine thickness of thin layers [2]. It is also worth to notice that presented technology can be applied to wafers residing on other transparent media such as grinding and dicing tapes.

Second particularly interesting application is related to measurement of thickness of light emitting structures comprising of thick buffer layers and thin active layer. The active layer comprises single or multiple quantum wells (MQW). Example of interferogram of reflected light collected from such structure is shown in Figure 4.

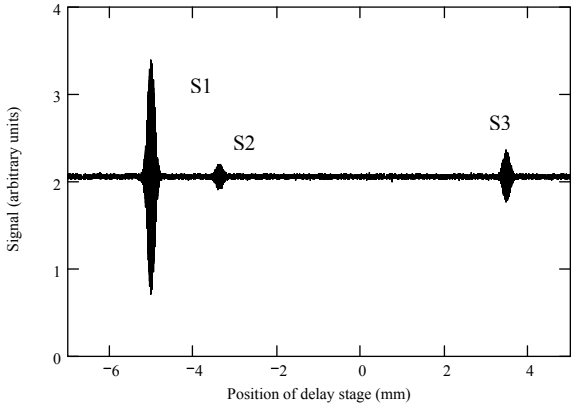

Figure 4: Interferogram of the radiation reflected from multiple quantum well GaAsP/GaP. Features S1, S2, and S3 correspond to reflections from front surface of the sample, MQW portion of the sample and back surface of the sample

ACCURACY AND REPRODUCIBILITY MEASUREMENT

Static reproducibility is 0.07 μm for the systems operating at rate of from 8 to 20 measurements per second. This relatively high speed of data acquisition and processing allows us to integrate sensor with XY translational stage and allows mapping thickness of measured wafers. In this place we would like to present example of measurement above described GaAsP/GaP structure illustrating dynamic reproducibility of our tool. Measurements were performed on 75 mm diameter wafer mounted on tape, at five different points. Origin of our system of coordinates resides at the center of the wafer. Flat of the wafer resides on negative portion of y-axis. Results of the measurement are presented in Table 1. They indicate that dynamic reproducibility of the system is of the order of 0.1 μm to 0.3 μm.

We reported earlier detailed validation studies of our technique [2], which indicated that absolute accuracy of the tool is generally better than 0.5 μm for samples with well-known refractive indices.

TABLE I
REPRODUCIBILITY OF MEASUREMENT TECHNIQUE

Measured Point					
Position (x,y) (mm,mm)	(0,25)	(0,0)	(0,-25)	(-25 ,0)	(25,0)
Measure-ment number	Measured Thickness (μm)				
1	253.7	258.2	253.6	255.7	253.2
2	253.8	258.1	253.6	255.8	253.5
3	254.0	258.0	253.5	255.9	253.7
4	254.0	258.3	253.8	255.7	253.7
5	253.8	258.3	253.8	255.9	253.9
Average	258.2	258.2	253.6	255.8	253.6
Stdev	0.2	0.2	0.2	0.1	0.3

CONCLUSIONS

We have presented novel method for measuring thickness of mounted compound semiconductor wafers. Presented can be readily applied in-situ applications.

REFERENCES

[1] D. Huang, E. A. Swanson, C. P. Lin, J. S. Schuman, W. G. Stinson, W. Chang, M. R. Hee, T. Flotte, K. Gregory, C. A. Puliafito, J. G. Fujimoto, "Optical coherence tomography," Science 254, 1178-1181 (1991).

[2] W.J. Walecki, R. Lu, J. Lee, M. Watman, S.H. Lau, A. Koo, "Novel non-contact wafer mapping and stress metrologies for thin and ultrathin chip manufacturing applications" 3 rd International Workshop on Thin Semiconductor Devices – Manufacturing and Applications November 25, 2002, Munich, Germany

ACRONYMS

MQW: Multiple Quantum Wells