A New Technique for Ultrasonic Thickness Measurement of Thin Film

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1. Introduction

Measurement technique of thin film to monitor the amount of etching thickness and the remaining time to stop the etching process is very critical in semiconductor industry to assure the quality and performance of production line of wafers. Traditional measurement techniques widely used in plasma etcher and wet etcher, measures the film thickness using laser based interferometry and optical emission spectrometry. However, in spin etcher, recently developed etching technique, the wafer is etched using chemicals while is rotates at a very high speed wafers. Single wafer processing(SWP)replacing the traditional wet bench is a technique that performs a series of processes including all of cleaning, etching, and drying in one chamber where wafers are fed one by one automatically by a robot system and several equipments such as spin etcher assembled together. SWP is very effective and cost saving for 12" wafer processing line, so that it is expected to be adopted in major semiconductor manufacturers. Thickness measurement is vitally necessary to ensure the performance and effectiveness of SWP. However in the spin etcher it is difficult to measure the thin film thickness because the optical signal from the thin film in traditional optical techniques would deteriorate due to the fluid flow and the fume generated by the chemicals the leading to an inaccurate measurement. More important problem of the optical methods is that metallic film is not optically transparent and cannot be measured by the optical techniques.

In this paper a new ultrasonic measurement method is developed and proposed for measurement of thin films.

2. Ultrasonic interference model in thin film

Rose[4] had investigated and reported the useful aspects of thickness measurement technique of oil film sandwiched by two identical plexiglas plates using amplitude of total reflected wave from the oil film. The idea is that the amplitude of total reflection wave goes to zero proportionally as the thickness of oil film decreases to zero as shown in Fig1.This relationship appears in the region where the oil film is thin less than 20m. The sensitive region in Fig1 may be narrower or wider according to the frequency of incident waves. Therefore simple measurement of the amplitude of total reflection waves from the oil film can yield the thickness of oil film directly from the diagram in Fig 1.However, although the high sensitivity can be seen when the film thickness is very small, signal-to-noise(SNR) becomes small too, which is not desirable for the measurement of submicron film thickness. The amplitude of total reflected wave is no longer useful for the measurement of the oil film thickness. Form mathematical medel in Fig 2, total reflection wave f(t+kx) is expressed by using incident wave $f_0(t+kx)$ as following[1,2]

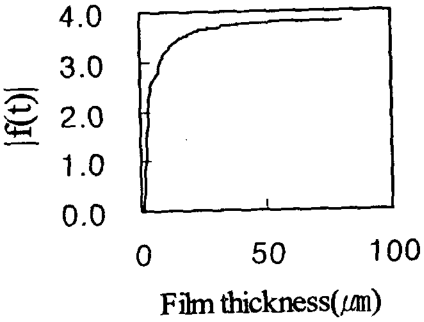

Figure 1. Reflection wave from a thin film

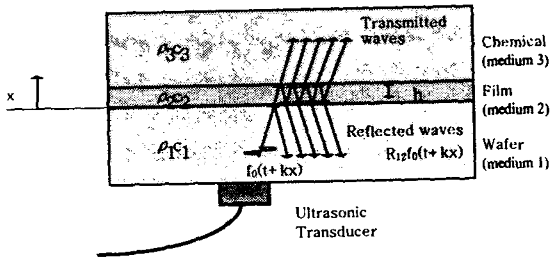

Figure 2. Reflection and transmission in thin film

$$f(t+kx)=R_{12}f_0(t+kx)+\frac{T_{12}T_{21}}{R_{21}}\sum_{m=1}^{\infty}(R_{21}R_{23})^m f_0(t+kx-2msh) \qquad (1)$$

where,s is the slowness of the waves, i.e.s = 1/wave velocity. R_{12}, R_{23}, T_{12} are reflection and transmission coefficient when the wave travels from medium 1 to medium 2, given by[3].

$$R_{12}=\frac{\rho_1c_1-\rho_2c_2}{\rho_1c_1+\rho_2c_2} \quad T_{12}=\frac{2\rho_1c_1}{\rho_1c_1+\rho_2c_2} \qquad (2)$$

If we define the second term in the right-hand side of eq.(1) as g(t+kx) which is the sum of consecutive reflected waves from the second boundary surface at x=h, Eq.(1) is expressed at x=0 by

$$f(t)=R_{12}f_0(t)+g(t),\ \text{where}\ g(t)=\frac{T_{12}T_{21}}{R_{21}}\sum_{m=1}^{\infty}(R_{21}R_{23})^m f_0(t-2msh) \qquad (3)$$

g(t) may be thought the difference between the total reflected signal f(t) and the first reflected signal $R_{12}f_0(t)$ from the first boundary surface(x=0). When the layer becomes thin enough relative to the pulse duration that the echoes g(t) superimpose, then the overall amplitude of the total reflection wave f(t) is affected. Using Fourier form of the term $f_0(t-2msh)$, Eq.(3) is expressed as if $R_{12}=R_{23}$ for convenience.

$$g(t)=\frac{T_{12}T_{21}}{R_{12}}\frac{a_0}{2}\sum_{m=1}^{\infty}R_{12}^{2m}+\sum_{m=1}^{\infty}\sum_{n=1}^{\infty}R_{12}^{2m}a_n\cos[n(t-2msh)]+\sum_{m=1}^{\infty}\sum_{n=1}^{\infty}R_{12}^{2m}b_n\sin[n(t-2msh)] \quad (4)$$

where, $a_n=\frac{1}{\pi}\int_0^{2\pi}f_0(t)\cos(nt)dt$, $b_n=\frac{1}{\pi}\int_0^{2\pi}f_0(t)\sin(nt)dt$, $n=0,1,2....$

Rearranging and simplifying the equation (4) yields

$$g(t) = R_{12}T_{12}T_{21}\left\{p(t-2sh) - R_{12}^2\,p(t)\right\} \quad (5)$$

where, $p(t) = \sum_{n=1}^{\infty}\alpha_n\{a_n\cos(nt)+b_n\sin(nt)\}$, $\alpha_n = \frac{1}{1+R_{12}^4-2R_{12}^2\cos(2nsh)}$

This characteristic of $|g(t)|$ is illustrated in Fig 3,where the amplitude change of $|g(t)|$ is normalized with respect to the amplitude of $R_{12}f_0(t)$. Since $f_0(t)$ is arbitrary ultrasonic pulse signal, an ultrasonic signal from 5MHz ultrasonic transducer is used to obtain the waveform of $R_{12}f_0(t)$.

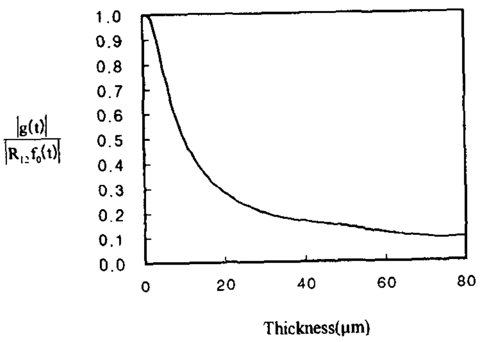

Figure 3. Correlation of $|g(t)|$ with film thickness

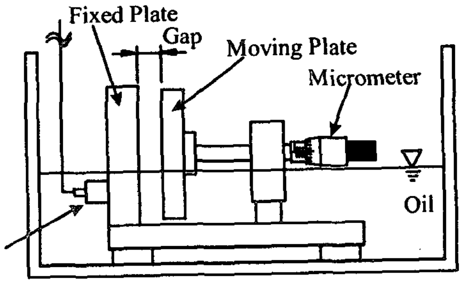

Figure 4. Experimental set-up for thin oil film.

3. Experiment and results

An experimental set-up for the measurement of an oil film thickness is shown in Fig. 4 to verify the method presented in the paper. A moving plate is mounted at the end of the micrometer which controls the thickness of a gap between two plates, the moving steel plate and fixed steel plate. On the back side of the fixed plate 5MHz ultrasonic transducer is attached to send and receive the ultrasonic signal. The oil gap is set 500㎛ at first large enough to separate reflection waves from two boundary surfaces for the measurement of the first reflection wave. $R_{12}f_0(t)$. The gap is decreased down to zero(contact) successively while measuring the total reflection wave f(t) from the oil layer between two plates at each step.

Then g(t), the signal of our interest, is calculated simply by subtracting R12f0(t) from f(t) in time domain. Results are shown in Fig 6, where the surface roughness of the plate is approximately 1 μm and acoustic impedances of the plate and oil are 36.9× 10^6Kg/m^2s and 1.28× 10^6Kg/m^2s respectively.

A good agreement is observed between theory and experiment in Fig5.Especially the sensitivity in the region below 20 μm is so high that the oil film thichness can be determined with good accuracy from Fig 6 even though the thickness of oil film becomes very small, much less than 0.1 (wavelength). Once the magnitude of g(t) is measured, the corresponding oil film thickness is obtained directly from the relationship shown in Fig 6 without any further data processing or calculations.

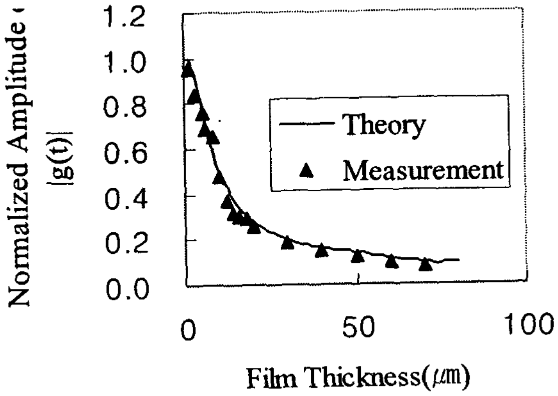

Figure 5. Relationship between |g(t)| and film thickness

4. Conclusions

A simple ultrasonic method with high sensitivity for thin film less than one-tenth of wavelength(0.1λ) was suggested and tested to investigate a possibility for the measurement of the deposited films of wafers. Mathematical model and expression for the technique was made with discussion to determine the thickness of thin film with accuracy and speed. Very thin oil films ranging from zero to 80λm in thicknes were measured using relatively low frequency transducer(5MHz),and compared with theoretical calculation. A very good agreement is found and experimental results showned that the thickness measurement technique described in this paper can provide a precise and fast tool for the measurement of thin films including metallic film in the etching process.

References

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