Invited

In-situ Measurements on Films on Silicon

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The requirements for single wafer processing must include the ability to monitor in real time during the process the important process parameters. Optical techniques meet most of the stringent microelectronics process requirements: non destructive, non invasive, automated, sensitive, yield fundamental parameters, has some in-situ precedent. The present review of our recent research with in-situ ellipsometry, differential reflectance and film stress measurements shows the applicability of the techniques to some processing problems.

Introduction

The single Si wafer processes that were developed in the 1970's and 1980's in research laboratories around the world are now being seriously contemplated for use in manufacturing. These processes are typically vacuum chamber processes and the chambers can be clustered, in order to construct a process With a Si wafer entering the first line. sorting and cleaning chamber, and not exiting the connected process chambers until the wafer is finished to the point of dicing, bonding and final packaging, there exists the requirement for in-situ monitoring of the progress and quality of each of the process steps. Not only must the ideal process monitoring techniques be capable of analyses in the vacuum chamber environment, but also during the process, in order that automated controls can adjust the process to meet specifications. Post process vacuum chamber analyses are rather straightforward and have been highly developed in the surface science disciplines over the past twenty years with such techniques as the electron diffraction and electron spectroscopies being the most notable classes of techniques. However, these powerful and necessary techniques take an ancillary role for in-situ during process monitoring, ISDP, since they are neither

sufficient nor operable for ISDP analyses. From simplistic reasoning it is easy to construct a set of requirements for ISDP monitoring. First, the monitor must not be destructive of the material probed. Low power/intensity probe beams must be adequate. Second, the ISDP monitor must not alter the process, that is it must be non-invasive. The ISDP monitor must be sensitive to subtle materials changes, automated, with clearly established scientific precedent, capable of monitoring many process steps, as well as simple, rugged and of course inexpensive. It is obvious that our probably incomplete set of requirements has eliminated all known analytical techniques. Thus compromises must be made.

The present review covers the last several years of work in our laboratory on adapting several optical techniques that we have used and are presently using to study the basic physics and chemistry of thin film and surfaces. We discuss the techniques of ellipsometry with spectroellipsometry, SE, differential reflectance, DR, and film stress measurements, all of which are applied ISDP.

Ellipsometry

Ellipsometry (reflection ellipsometry) measures the change in polarized light upon

reflection. Essentially, two parameters of the reflected light are accessed, the amplitude change, ψ , and the phase change Δ between the p and s components of the light are compared before and after reflection and yield the complex reflection coefficient, ρ . The detailed derivation of the relationships are well documented¹, and will not be emphasized in this review. However, it is well to keep in mind that the complex dielectric function, ϵ , is obtained directly from ρ , and that ϵ is a composite function of the refractive index, n, and the absorption index, k. For film covered surfaces а pseudodielectric function, $<\epsilon>$ is obtained which is also a function of film thickness. It has been shown by many studies, principally the work of Aspnes^{2,3}, that many film growth and damage processes are best modelled using the Bruggeman effective medium approximation which provides the recipe for obtaining ϵ for inhomogeneous films when the constituents and their dielectric functions are known. The calculated ϵ and the experimental values are compared using an error minimization algorithm which then yields the best fit values for film thicknesses and the volume fractions of the constituents. Fig. 1 shows one example of the comparison for the modelling of low energy Ar+ ion beam damage ISDP studies4,5. The model used and the best fit parameters are shown in the inset. Other examples such as extensive ion beam damage and etching results will be shown as well as modelling for thin SiO2 films.

Differential Reflectance

Differential reflectance, DR. as practiced in the present study compares two samples according to the near normal incidence reflection characteristics^{6,7}. By scanning the incident light across two adjacent samples and using lock in amplification tuned to the scanning frequency after the detector, only the difference in reflection of light from the adjacent samples is sensed and measured. This technique yields far greater sensitivity than would be obtained from a measurement of the reflected light from a single sample. The reason for the greater sensitivity is that samples are rapidly compared so as to remove the effects of source fluctuations and/or interferences. We believe that this technique is particularly well suited to ISDP because it is simpler than ellipsometry, requires only one chamber port and it should have sufficient sensitivity for most applications.

In Fig 2 is shown data from an ex-situ study of ion implantation, I/I, damage as caused by the implantation of Si⁺ implanted into a Si surface. For the DR measurement an I/I sample is placed adjacent to a clean undamaged c-Si wafer surface. With the I/I surface amorphized by the ion sample bombardment yielding the featureless reflection spectrum of a-Si, compared with the sharp featured reflection spectrum of pristine c-Si which shows the E1 and E2 interband peaks at 3.4 eV and 4.2 eV, respectively, the difference spectrum would show primarily the features of the c-Si. Spectra taken at various energies and doses will be presented and applications ISDP for the chemical etching of SiO, films on Si in HF/H2O solutions will be presented.

Film Stress

The film substrate interface almost always experiences stress since two dissimilar materials meet at that interface. For Si wafers the stresses may be sufficient to cause a deformational bending of the wafer. This bending can be measured by the divergence of two perfectly parallel light beams^{8,9}. The film stress during Si oxidation is shown in The SiO₂ stresses with Si Fig. 3. orientation, SiO₂ film thickness, oxidation temperature and ambient has been studied⁸⁻¹¹, as well as the ISDP formation of metal silicide stresses12.

It is shown that many techniques from the research laboratory can be applied to monitor modern chamber processes.

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References

1. R.M.A. Azzam and N.M. Bashara; <u>Ellipsometry</u> and Polarized Light, North Holland, Amsterdam, The Netherlands, (1977).

D.E. Aspnes; J. Vac. Sci. Technol. <u>18</u>(1981)
289.

3. D.E. Aspnes and A.A. Studns; Proc. S.P.I.E. 276(1981) 227.

4. J.W. Andrews, Y.Z. Hu and E.A. Irene; Proc. S.P.I.E. <u>1188</u>(1990) 162.

5. J.W. Andrews, Y.Z. Hu and E.A. Irene; Proc. Process Modelling Conf. Electrochemical Soc. Montreal CA, May 1990 in press.

6. R.E. Hummel; Phys. Stat. Sol.(a) <u>76(1983)</u> 11.

 T. Burns, S. Chongsawangvirod, E.A. Irene,
G. McGuire and Sopa Chevacaroeukul, to be submitted.

 E. Kobeda and E.A. Irene; J. Vac. Sci. Technol.B <u>4</u>(1986) 720.

9. E. Kobeda and E.A. Irene; J. Vac. Sci. Technol.B <u>5</u>(1987) 15.

10. E. Kobeda and E.A. Irene; J. Vac. Sci. Technol.B <u>6</u>(1988) 574.

11. E. Kobeda and E.A. Irene; J. Vac. Sci. Technol.B <u>7</u>(1989) 163.

12. P. Buaud, F.M. d'Heurle and E.A. Irene; to be submitted.



Fig. 1 Pseudodielectric function for 1.2 keV Ar⁺ of 5 x 10^{15} dose on c-Si with BEMA analysis⁵.



Fig. 2 Differential reflectance spectrum on Si^+ I/I into c-Si compared to c-Si⁷.



Fig. 3 Comparison of in-situ and ex-situ intrinsic stress measurements¹¹.

