Real-time, in-situ measurement of film thickness and uniformity during plasma ashing of photoresist

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ABSTRACT

This paper will discuss the performance of equipment which monitors and so controls photoresist thickness and uniformity during plasma ashing without interfering with the process. Practical monitoring of a subtractive process of this type is significantly more complex than monitoring deposition processes. An initial absolute thickness measurement is needed. In addition, the device must view the layer through a luminous medium, and cannot rely on simple optical interference fringe counting. The equipment is self-calibrating and sensitive to layers dnm thick. An application to partial plasma resist ashing in high uniformity equipment will be described. Application to other films (e.g. oxide) will be discussed.

1. INTRODUCTION

We report here on the development of equipment for on-line monitoring of photoresist ashing, and some of its applications. The original purpose was to develop a production worthy end point detector which would terminate ashing when a preselected thickness of photoresist remained on the wafer. This was required to operate in a production environment where the initial resist thickness was not known. Furthermore we required the instrument to operate without adjustment overdifferent underlayers which were arbitrarily patterned.

2. METHOD

An optical interference approach was chosen to solve this problem. Such a device measures optical thickness, but can be corrected for refractive index to give actual thickness. In principle each resist type has a different correction factor, but in this practice resists vary only a few percent in index and we simply used average values as sampling rate errors are more significant than this. Interference measurements at more than one wavelength are needed to give absolute thickness according to the equation which applies at normal incidence.

$$T = M/4\,(n_1/\lambda_1 - n_2/\lambda_2)$$

where T is the thickness, M is the number of half wavelengths between the measurement points at extrema wavelengths λ_1 and λ_2, and n_1 and n_2, respectively, the refractive index at these wavelengths.

This principle has been very widely used for measuring transparent film thickness and is the basis of a number of commercial instruments. In principle, interferometric ellipsometry would allow more precise measurements but the extra complexity, computer power and cost were not felt to be justified here.

The accuracy of this measurement depends on the ashing rate and the sampling time between successive thickness calculations. In a single wafer asher resist removal rates are typically one to three microns per minute, and a sampling rate of three to four per second is needed to approach 10nm termination accuracy. Thepractical limitation here was the computer calculation time.

3. EXPERIMENTAL DETAILS

The experimental arrangement is shown in Figure 1. The resist coated wafer is placed on a temperature controlled aluminum platen in the main chamber. The plasma is generated in a separate chamber, reaction products flow into the upper part of the wafer chamber then through a multi-holed quartz distribution plate to the wafer. The chamber top is a

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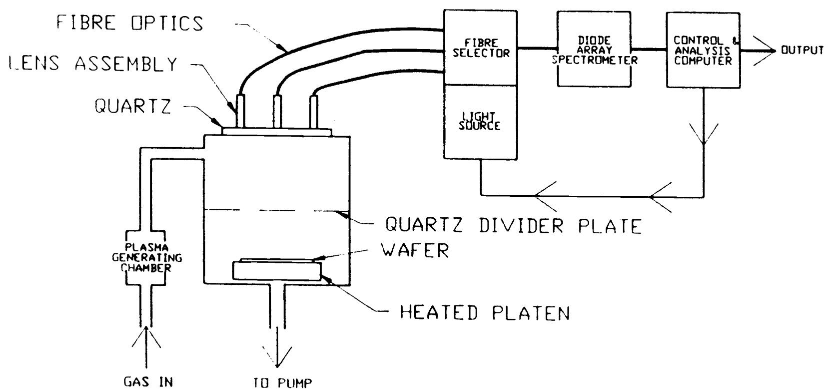

FIGURE 1.
EXPERIMENTAL ARRANGEMENT

quartz plate over which are mounted a set of five lens assemblies attached to individual cored optical fibres. These, in turn, connect through an optical switch to a white light source and a photodiode array spectrometer which analyses the returned light over the range 450 to 950nm. This chamber geometry is convenient since the light is at normal incidence, asimilar system with separate transmitting and receiving heads and fibres would allow operation at other angles of incidence. Light is collected from a 2mm diameter area of the wafer surface. This area is large compared to a typical wafer patterning scale so that the thickness measurement is not dependent on photoresist patterning (except for overall intensity). The conditioned signals from the photodiode array go to the computer which calculates the thickness after applying appropriate background subtraction and refractive index corrections.

Several features mentioned above combine to make the measurements relatively simple when compared with previous experiments The reactor chamber is designed for low damage downstream ashing, the plasma luminosity even in the upper part of the chamber is very low. There is no plasma in the lower chamber, and the chemiluminescence there is mostly outside the range of the spectrometer. The resist thickness can be monitored at up to five points, depending on the particular fibre output selected by the multiplexer under the computer control. The only penalty is the increased time between samples on a given head, which depends on the switching sequence.

4. RESULTS

The initial sampling rate of the instrument was limited by the on-screen display of results and printout. After simplifying the on-screen display and using a post run printout, a sampling rate of about one point per two seconds on a single head was attained using a 80286/80287 based computer running at 10MHz clock rate. Thickness could be tracked down to about 250nm. The thickness calculation algorithm was now the rate and thickness limiting feature. Improvements in this algorithm and its coding, and upgrading to a 80386/80387 based computer running at 25MHz brought the sampling rate to about three to four per second and extended the thickness measurement down to below 80nm. These figures were acceptable in view of the system requirements and uniformity. System accuracy as an end point terminator was better than 10nm, consistent with the theory of operation. The system has been tested on patterned and unpatterned wafers, with polysilicon and oxide underlayers. Preliminary results with metal underlayers are encouraging.

In Figure 2 we show some results which yield photoresist ash rate as a function of wafer temperature. As expected, the resulting rate/temperature plot can be fitted to an Arrhenius curve.

In Figure 3 we show a more interesting example of the ashing of heavily implanted resist. The results show the presence of a resistant top shell of implant damaged resist (probably highly carbonized) of thickness 300nm over a less resistant implanted bulk. The presence of this shell had been qualitatively inferred from other experiments, these results show very directly that its thickness is fairly well defined.

The multi-head sampling and uniformity measurements have not been pursued since it turned out to be unnecessary for our immediate applications. The normal ashing, uniformity of this arrangement is better than seven percent as measured by (max-min)/2 average at 50 percent ash. No difficulties are foreseen for the simple case of cyclically scanning up to five heads and computing individualthicknesses - the increased time between points is still well within the system calculation capabilities, as shown by the early experiments. For improved accuracy of termination, we can use a predictive algorithm based on measured ash rates.

STANDARD PHOTORESIST

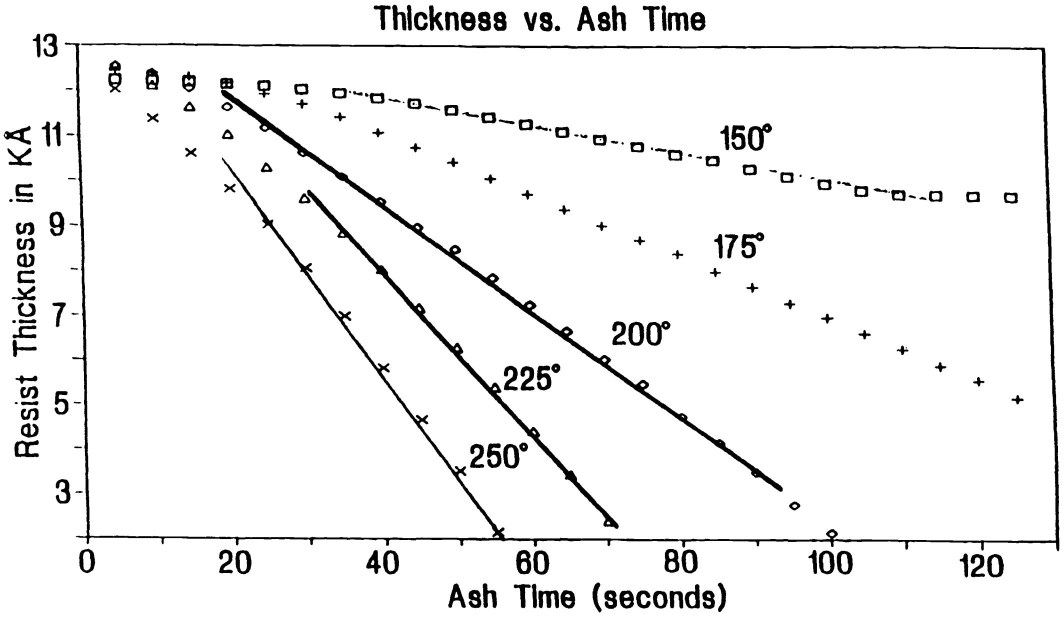

FIGURE 2

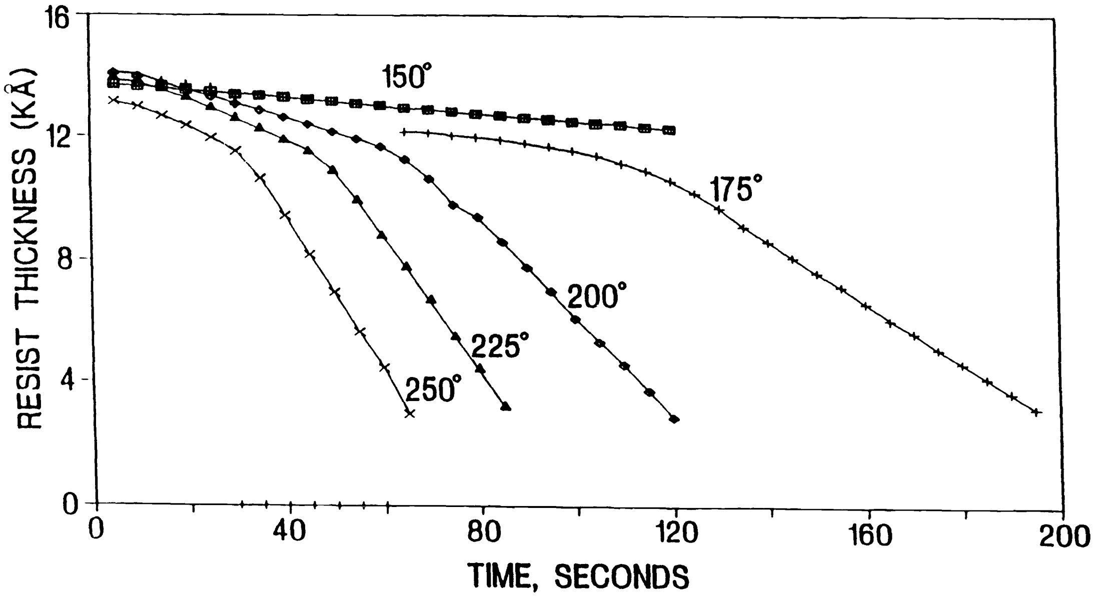

FIGURE 3

5. CONCLUSION

The equipment is quite simple and robust, and performs to the original design specifications. Its ability to measure actual process result parameters (film thickness and etch rate) on a realistic time scale allow it to be used as a sensor for real process control. Future work will be on other semi-transparent layers, e.g. oxide, nitride, after completing photoresist/metal underlayer characterization.

6. ACKOWLEDGMENTS

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7. REFERENCES

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