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Work by Prof. Smith and his collaborators is summarized here

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Distortion-Free X-Ray Mask Technology

Quarterly Technical Report
for the period
September 12, 1990 to December 11, 1990

by
Research Laboratory of Electronics
Massachusetts Institute of Technology
Cambridge, MA 02139

Principal Investigator

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Dept. of Electrical Engineering and Computer Science
Massachusetts Institute of Technology

January 11, 1991

Objective:

The objective of this research project is to develop a closed-loop, feedback-controlled, robust system for reliably achieving zero stress in tungsten (W) films sputtered onto various x-ray mask membranes, and to transfer the technology to the National X-ray mask shop. Our system for controlling stress in sputtered W films is based on the measurement of resonant frequency. Since resonant frequency depends on both the thickness and the stress of the W films, if the thickness is known, the stress is easily calculated from

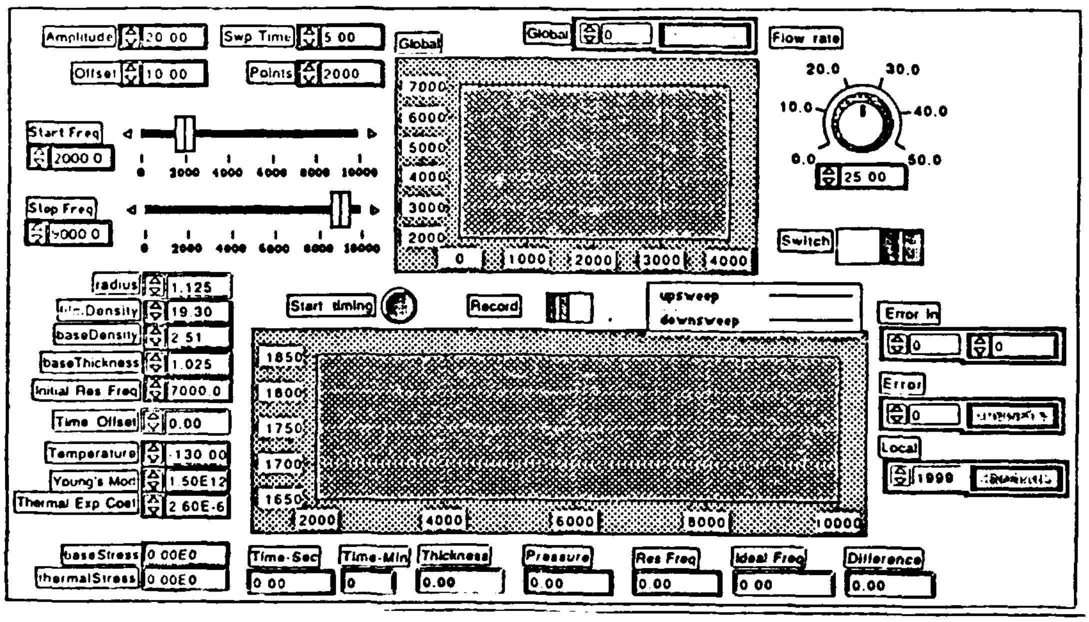
$$V_{res} = A \left[\frac{B + \sigma_W t_W}{C + D t_W}\right]^{1/2}$$

where A, B, C and D are constants, known in advance, σ_w is the tungsten stress and t_w is the W thickness.

Progress:

1. We have made a major improvement in the software that is used in the in-situ stress monitoring system. A LABVIEW II program from National Instruments is used to replace the original C program. This program is chosen to facilitate the interface between the operator and the MacII computer during the sputtering process. Figure 1 shows the front panel displayed during the deposition process. On the bottom left side of the panel is all the data required to describe the membrane properties (e.g. density, radius, initial stress, and thermal expansion coefficient) that are required for the computation of an empirical curve that we will try to follow during the

Fig. 1



deposition process. On the top left side of the display is the control panel for the function generator that we use to drive the membrane. Here we can specify the sweeping frequency range, driving amplitude, and number of data points to be collected for each frequency sweep. On the bottom of the display is a graphical display of the membrane response to the frequency sweep, and all the data extracted or measured for that particular time interval of data collection (i.e. the measured resonant frequency, the calculated resonant frequency, sputtering pressure and deposited W film thickness). On top of this graphical display is the resonant frequency of the membrane measured for the entire time interval of the sputtering process. Finally, at the top right of the display is the control panel for the mass flow controller, which allows direct setting of Ar flow rate into the sputtering chamber and therefore control of sputtering pressure.

2. We are in the process of doing extensive testing on the data acquisition and control program that we have written using LABVIEW II. Some initial results that we obtained are very encouraging. Figure 2(a-c) depict three different sputtering runs that shows the stress control with the in-situ set-up, by making the resonant frequency follow (or oscillate about) an empirically calculated curve. All three cases gave zero stress (i.e. <$5x10^7$ dynes/cm^2). The solid points are experimental measurements of the resonant frequency, and the solid curve is the calculated curve that the experimental measurements should fall on in order to maintain zero stress throughout the deposition.

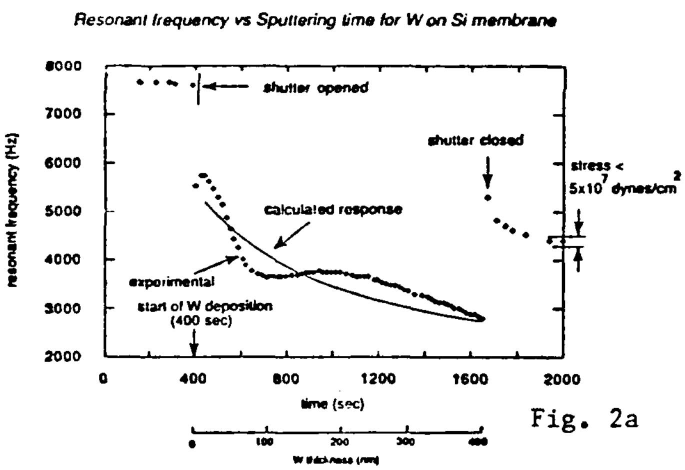


Fig. 2a

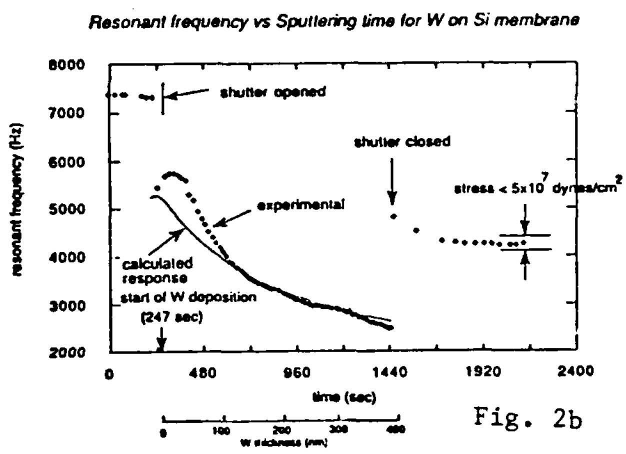


Fig. 2b

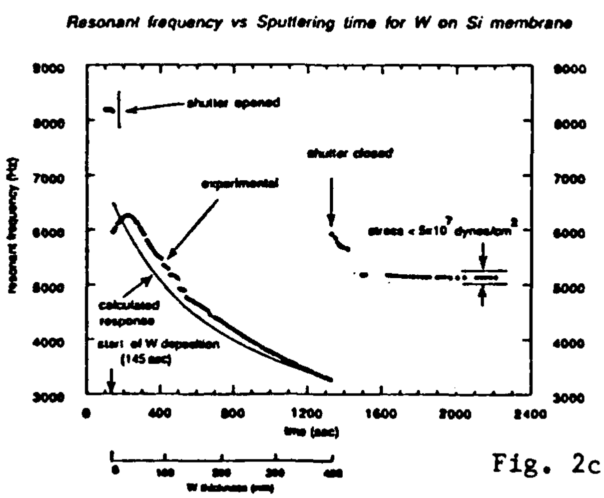


Fig. 2c

Note in Fig. 2a that the resonant frequency of the membrane is constant at 7800 Hz prior to opening the shutter and commencing the W deposition. As soon as the shutter is opened, the resonant frequency decreases by ~2kHz and then rises and settles down to follow the shape of the ideal curve after about 120 sec. We attribute this transient behavior to heating of the membrane. Because it is only 1 μm thick the membrane heats up rapidly once it is exposed to the plasma. This causes the sudden drop in resonant frequency. The corresponding change in stress is given by

$$\Delta\sigma = -\alpha_m E_m \Delta T$$

where ΔT is the difference in temperature between the membrane and the more massive supporting substrate, α_m is the coefficient of thermal expansion of the membrane, and E_m is Young's modules. For a Si membrane ($\alpha = 2.6\text{x}10^{-6}\,K^{-1}$, $E = 1.6\text{x}10^{-12}$ dynes/cm^2). A drop of 2kHz corresponds to a $\Delta\sigma$ of 5-6x10^8 dynes/cm^2. This corresponds to a ΔT of 120-140°C, which is about the expected temperature rise based on the power input to the membrane and the thermal conduction. The slower (~ 100 sec) rise is resonant frequency after the rapid initial drop is attributed to heating of the supporting substrate around the perimeter of the membrane which reduces the temperature gradient ΔT, causing some of the membrane stress to be restored. Note that this transient behavior (rapid shift of ~ 2kHz followed by a slower shift in the opposite direction of < 1kHz) is repeated at the end of the sputtering run, as it should be. That is, the membrane also cools much more rapidly than the supporting substrate.

3. *We have improved the RIE of tungsten by using new gas combinations* of CHF_3/SF_6 that are mixed at a flow ratio of 1.8-2.3:1 at a bias voltage of 600V, a pressure of 10mtorr, and power density of 0.41 w/cm^2. Figure 3 show the etch rate variation as we slowly increase the SF_6 flow rate in CHF_3.

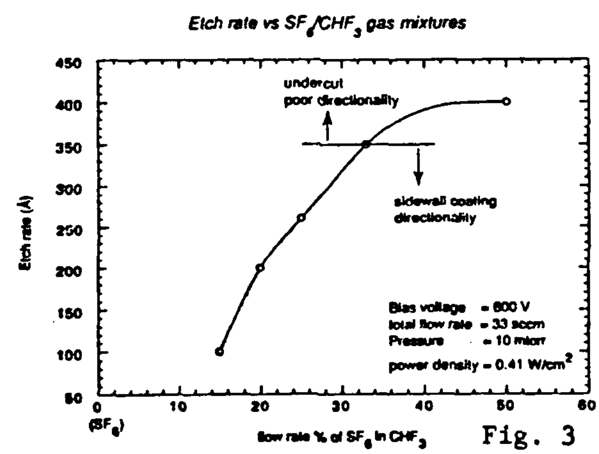


Fig. 3

<u>Summary:</u>

In summary, we have passed our scheduled milestones; our progress is ahead of schedule.

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