SILICON PROCESSING I.

THE TRUE SURFACE TEMPERATURE OF A SILICON WAFER AND THE RELATED ETCH RATE IN A CF_4 PLASMA

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Résumé. — Nous avons diffusé une structure de thermomètre à résistance dans une tranche de silicium pour mesurer l'accroissement de la température surfaciale de cette tranche en plasma d'attaque de CF_4 . En l'espace d'une minute la température monte jusqu'à plus de 100 °C. Contrairement la température du système augmente seulement de 5 °C pendant le même temps. Ce résultat se rapporte à un système cylindrique. Dans un système d'attaque capacitif des disques parallèles, la température de la tranche s'accroît plus lentement et s'aplatit après trois minutes.

Nous avons mesuré la vitesse d'attaque entre la température ambiante et 100 °C. Nous avons trouvé que l'influence de la température est insignifiante et n'est pas utile à contrôler la vitesse d'attaque.

Abstract. — By means of a resistance thermometer structure diffused into the surface of a silicon wafer the temperature has been found to increase within a minute to over 100 °C in a CF_4 plasma. In contrast the system temperature rises only about 5 °C in the same time. This applies to a system in the tunnel configuration. In a parallel plate system the rise is far less steep and even within the usual etching time an equilibrium temperature is reached. The dependence of the etch rate on the surface temperature has been measured. In the interval from R.T. and 100 °C the etch rate stays nearly the same. Therefore temperature is no significant parameter for establishing desired etch rates.

1. Introduction. — In wet chemical reactions we experience the temperature as an important parameter for the reaction speed. The etching processes in semiconductor device manufacture are usually accelerated by warming the etch solution, or if critical surfaces are involved, the etchant may be cooled to slow down the reaction.

Similarly application of external heat has been suggested for plasma etching systems [1, 2]. The intention seems to have been twofold. First, if the temperature causes a non-linear etchrate, temperature control may be used to linearize it and to permit determination of the end point of the process. Second, a high wafer temperature is considered favourable for the removal of reaction products so that always a free surface is exposed to the oncoming radicals. In this connection the temperature of a cylindrical etch tunnel system has been measured as shown in figure 1. In the first few minutes this temperature rises moderately and sooner or later, depending on RF-power and gas pressure, it levels off. From this behaviour some workers in the field (3) have derived the recommendation to first heat the system into the *constant-temperature* region by means of a discharge in an inert gas, e.g. nitrogen, and only then start the actual etching process.

The influence of the temperature on the etching process has been measured by various researchers [2, 3, 4, 5, 6, 7]. Not all results of these investigations agree. Some show a considerable variation of etch-rate with temperature whereas others found no

FIG. 1. — System temperature of a tunnel etching reactor when a $\text{CF}_4 + 4\% \text{O}_2$ plasma is employed.

significant effect. Not in every case is the method of thermometry explicitly described. To electronically measure the temperature in a RF-field entails serious difficulties. Points on the silicon wafer connected to ground, for instance *via* a thermocouple, may receive preferred bombardment with charged particles. The walls of the etching system or any internal parts may differ widely in temperature from the wafer, because black body conditions are not realizable.

These circumstances have prompted us to develop a method, which allows to measure the true surface temperature of the wafer and to relate the latter to the etch rate of silicon (100) in a $\text{CF}_4 + 4\% \text{O}_2$ plasma.

2. **Experimental.** — A resistance structure was diffused into the surface of a (100) n-type silicon wafer of 2" diameter by standard silicon device technology (Fig. 2). This resistor was then connected into a bridge circuit and used as a resistance thermometer. It was calibrated inside a completely closed oven

FIG. 2. — Silicon wafer resistance thermometer.

against a Ni-NiCr thermocouple and showed a perfectly linear resistance-temperature characteristic (Fig. 3). This silicon wafer was placed inside the etch tunnel on teflon feet so that there was no metallic contact to any parts of the reactor. During the time the plasma was ignited the thermometer was completely disconnected from the rest of the bridge circuit. At the very moment the plasma was switched off, the bridge circuit was connected with the resistance thermometer and balanced to give a temperature reading. The silicon wafer cooled off fairly fast and at first the measurements were inaccurate. But after several trials one knew approximately the balance conditions before the plasma was switched off. The remaining unbalance signal was fed into a $Y-t$ recorder the Y axis of which was calibrated against resistance deviations from balance. Less than half a second after the plasma extinguished the recorder drew the unbalance signal as a function of time, which added to the bridge readings established the true

FIG. 3. — Resistance-temperature characteristic of the silicon thermometer.

temperature of the wafer. The maximum error was $\pm 2^\circ\text{C}$ at the higher temperatures where the cooling is fastest. It can be reduced further by extrapolation of the cooling curve. This method has been found far superior to a modern digital ohm meter because of the dynamic behaviour of the temperature.

3. **The wafer temperature under various plasma conditions.** — The first measurements were done in a nitrogen plasma using a tunnel reactor with various pressures and RF-energies applied (Fig. 4). Already here it became apparent that the wafer temperature increased much faster than the system temperature and within an etching time of 4 minutes rose to values never reached by the system not even after half an hour. This was even more drastic in the actual etching gas $\text{CF}_4 + 4\% \text{O}_2$ where the temperature exceeded within one minute 100°C . Under these conditions an electronic temperature control is rather difficult.

FIG. 4. — Temperature rise of a silicon wafer surface under various plasma conditions in a tunnel etching system.

In a parallel plate system the surface temperature rose moderately and at about 3 min flattened off (Fig. 5). The wafer was not in direct contact with the anode plate but was resting on teflon supports to establish unambiguous conditions with respect to thermal and electrical isolation.

4. **The dependence of etch rate on temperature.** — It is quite clear from the preceding section that a dependence of the etch rate on temperature is difficult to verify. To get as close to a true reading as possible with such a rapid temperature rise, we built a heatable etch tunnel in which we placed our resistance thermometer. In close contact with this we brought the silicon (100) etching sample. Both were well insulated against heat- and electrical-conduction from the tunnel. The temperature as read by the silicon ther-

FIG. 5. — Temperature rise of a silicon wafer surface in a parallel plate system — anode coupled.

meter was set to various temperatures from 23 °C (R.T.) to 100 °C. Then the etching plasma was switched on for 1 minute. After this the etched depth was measured with a stylus drawn across the step. Thus the data of figure 6 were obtained. Over the range covered the etch rate varies certainly less than 10 %, a rather insignificant amount, too little to make the temperature a usable parameter for establishing desired etch rates. If one then considers the damage inflicted upon the photoresist through exposure to high temperatures it seems a reasonable recommendation to accept room temperature as the ideal starting point for an etching process.

FIG. 6.

5. Conclusion. — When etching silicon in a CF_4 plasma the temperature of the wafer rises sharply, much more than can be inferred from knowledge of the system temperature. The etch rate is not significantly dependent on temperature. Therefore the increase of the etch rate with RF power is not related to the increase in thermal energy but exclusively to the higher amount of radicals generated. Similarly any change of etch rate with pressure is not the consequence of changed thermal conductivity of the gas but related only to the presence of different amounts of active gas molecules.

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