1. Proximity Heating Of Silicon Wafer

Lithography is a critical processing step in fabrication of advanced microcircuits. It transfers a circuitry layout from a photomask to a silicon wafer. A layer of photosensitive polymers (photoresist) is first spin-coated onto the silicon substrate. A lithography system then projects the image of the photomask onto the resist coating and creates a latent image in the resist. The photoresist in the exposed (or un-exposed) area is then removed by chemical etching

The latent image needs to be activated before the etching process. This is accomplished by setting the wafer temperature to around 180 C for a few seconds; etching quality control requires the temperature to be uniform to within 2 C over the entire wafer surface. A hot-plate heating technology is currently used. The wafer is first supported at ~2.5 cm away from the hot-plate surface. The wafer is then released and lowered quickly to a close proximity (of preset distance) of the hot plate. After a certain amount of heating time, the wafer is lifted away from the hot plate, picked up by a robot and then placed on a chilled plate to cool down.

It is important to reduce the wafer heating time in order to increase process throughput: the thermal activation time for the photo-resist only requires a few seconds at 200 C. You are hired as a consultant by a semiconductor equipment company to identify parameters that will affect the wafer heating rate, to establish a model that can accurately predict the transient wafer temperature, and to propose techniques to reduce the heating time and thus increase process throughput.

Specific questions to be addressed are:

a) Are the steady state temperature differences between the hot plate and the wafer as a function of the gap size consistent with the theoretical model of the heat transfer processes?
b) What does the heat-up time (either (1-1/e) or 10-90% rise time) depend on? Is your theory consistent with the measurement?
c) It is known that the heating process is faster with a smaller gap (δ) between the hot plate and the wafer. However, the dimension of a small gap is difficult to control – if the wafer is tilted a little bit (at an angle α) with respect to the hot plate, there will be a temperature gradient across the wafer surface. Discuss the trade-off between the heating time (τ) and the tolerance on α. For example, if the wafer temperature is to be 200 ± 1^{o}C, and α is accurate to 2 milli-radians, what should δ be, and what is the heat up time? How much faster will the heat up time be if the tolerance on α is improved to 1 milli-radians

Experiment

A simplified hot-plate heating experiment has been set up in the lab. A typical test run includes the following steps:

1. Place small pieces of paper around the edge of the hot plate as spacers for setting the gap between the hot plate and the wafer.
2. Lower the test wafer onto the hot plate. The distance between the wafer and hot plate is determined by the paper thickness.
3. Measure the plate temperature and the transient wafer temperature.
4. cool the wafer by lifting the wafer away from the hot plate after the wafer temperature has reached a steady-state value.

The hot-plate temperature should be set between 120 C and 180 C. (The paper spacer will char if the temperature is too high.) You should investigate experimentally the significant effect of wafer-plate distance on the wafer heating rate.

(Note: the thermal properties of silicon may be found on the web.)