OP-A: OPERATION OF HIGH TEMPERATURE FURNACES

filename: FURNAC

Our laboratory uses several different kinds of high temperature ($T > 400^{o}C$) furnaces to perform a variety of processes. These furnaces have many common features, and the purpose of this section is to familiarize you with their operation. The first and most important characteristic is the cleanliness of the furnace quartzware. Semiconductor processing is very sensitive to contamination, especially when the contaminant is exposed to high temperatures. For instance, doping levels of importance in silicon often are as low as $10^{15}/cm^3$; compared to normal atomic densities of 10^{22} atoms/cm^3, this is only one part in ten million. Because of this we use only extremely inert materials like pure quartz (SiO_2) in our furnaces. You must NEVER handle quartzware unless you are wearing clean gloves; finger oil is one of the worst sources of contamination. Also remember that if you touch your face while wearing gloves, the gloves will carry oil to anything you subsequently touch. **PLEASE HANDLE ALL QUARTZWARE CAREFULLY; ALWAYS ASSUME BOATS AND PULL RODS WILL BE VERY HOT. These boats, tubes, and rods were all custom made for our lab; they are both fragile and expensive.**

FURNACE GAS SYSTEMS

All the high temperature processing steps we perform must be carried out in controlled atmospheres. Each furnace has all the necessary gases plumbed to it; for each gas there is a TOGGLE VALVE which turns the flow on or off, and a FLOW METER - NEEDLE VALVE combination which sets the gas flow rate into the furnace tube. Gas flow is reduced when the needle valve is turned clockwise, and increased when turned counterclockwise. Flow rate is measured using a rotameter. This device is simply a tube with a tapered bore, which contains a small ball (see Figure 15). Higher gas flow rates cause the ball to rise higher in the tube. The diameter of the tube at the inlet, the weight of the ball, and the taper of the tube set the range of the rotameter. We use several different meter ranges, and each tube contains both a light ball (the black ball, made of pyrex) and a heavy ball (the silver ball, made of stainless steel), which doubles the effective flow range that can be measured. Table 10 summarizes flow rate settings used in the different furnaces. Most of these rates are chosen to simply prevent backflow from the room atmosphere into the furnace tube.

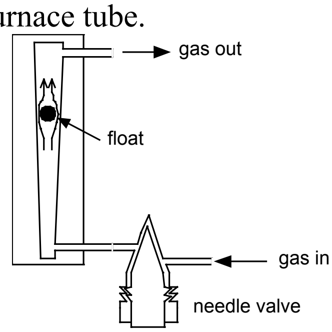

Figure 15: Cross-section of a rotamer type flow meter.

TEMPERATURE CONTROLLERS

All of our furnaces are resistance heated. By using a thermocouple to measure the temperature deviation from some set point, the furnace controller either increases or decreases the current supplied to the furnace. Using this relatively simple operating principle, carefully designed furnaces and controllers can maintain temperatures near 1000^{o}C with an error of only ± 1^{o}C. One important point to remember is that the thermocouple is located at only one place, and there can be appreciable temperature gradients in the rest of the furnace tube. For instance, there is obviously much more heat lost out the ends of the quartz tube than out the middle. If you measure the temperature profile from one end of the tube to the other, only a small region near the center (which is where the thermocouple is located) is fairly constant. This is called the flat zone of the furnace. Furnaces like our boron and phosphorus pre-dep systems have a flat zone of about 8 cm where the temperature varies only ± 1^{o}C.

Our larger furnaces (wet and dry ox, and drive-in) use a more sophisticated design to achieve a longer flat zone, shown schematically in Figure 16. These furnaces are known as 3-zone systems, since there are three independent heating elements. By applying more power to the zones at the ends of the tube, heat loss there can be compensated, and very long flat zones can be obtained. The controllers in these furnaces actually use a pair of thermocouples to measure the temperature difference between the center and the end. We use the center 10-turn pot on the control panel to set the flat zone temperature, and the other 10-turn pots to set the temperature difference. A setting of 500 on these pots would force the end temperature to equal the center; a setting less than 500 gives cooler ends, and greater than 500 gives hotter ends. We actually want the temperature at the ends to be cooler, so we use a controller setting of 100. Even so, these furnaces produce a flat zone (± 1^{o}C) over 20 cm long. Table 11 gives the furnace controller settings used, along with the actual temperature inside the quartz tube, as measured by a thermocouple probe. Note the stand-by settings used when the furnaces are not in use; it is necessary to keep the quartz tubes hot at all times to prevent them from de-vitrifying.

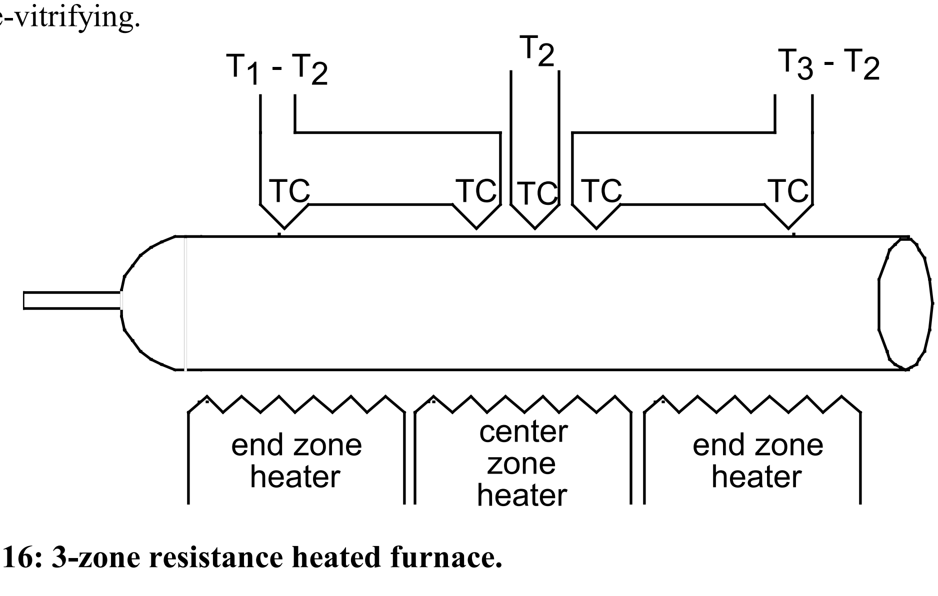

Figure 16: 3-zone resistance heated furnace.

REFERENCES

"Trends in Automated Diffusion Furnace Systems for Large Wafers," J. Maliakel, D. Fisher, Jr., and A. Waugh, "Solid State Technology," December, 1984, pp. 105-109.

Table 10: FURNACE GAS FLOW RATES

FURNACE	TUBE VOLUME (cc)	N_2		O_2		TCE		H_2O	
		cc/min	set pt	cc/min	set pt	cc/min	set pt	cc/min	set pt
Boron pre dep	1600	325	70	0	0	N/A	N/A	N/A	N/A
Phos. pre dep	1600	325	70	0	0	N/A	N/A	N/A	N/A
Drive-in	6700	1000	66 (pyrex)	1000	66 (pyrex)	N/A	N/A	N/A	N/A
Wet ox	6700	0	0	3000	100 (steel)	N/A	N/A	300	150 (steel)
Dry ox	6700	3000	100 (steel)	1000	66 (pyrex)			N/A	N/A

Table 11: FURNACE CONTROLLER SETTINGS

Furnace	Operation		Stand-by	
	Temp. (˚C)	Setting	Temp. (˚C)	Setting
Boron Pre-dep	950	926	650	650
Phos. Pre-dep	650	929	650	650
Drive-in	1100	100/395/100, 900 scale (check for updates)	600	100/100/100, 500 scale
Wet ox	1050	100/260/100, 900 scale (check for updates)	600	100/100/100, 500 scale
Dry ox	1100	100/445/100, 900 scale (check for updates)	600	100/100/100, 500 scale