October 15, 1993
STAR NOTE# 130
E. Paganis* C. Naudet**

TEMPERATURE MEASUREMENTS AND CALIBRATION ON SILICON DRIFT DETECTORS

1. INTRODUCTION

The bulk temperature of silicon is a very important factor in the performance of the Silicon Drift Detectors (SDD) because mobility and hence the drift velocity depend on it.

In the present note the most recent results are presented, concerning temperature measurements on two SDD detectors: the older n-type #261 and the recent and more developed n-type #416. First we study the effectiveness of the bulk in charge injection pads for calibration applications. Then we give the results for temperature stability test on 261 without cooling and with cooling during one hour of operation and compare. We make a temperature map for the 416 detector using an adjustable probe in order to check for the existence of temperature gradients along the drift direction or perpendicularly to it. Finally we present the first results concerning the mobility-temperature relation which gives us information about the temperature effect to the position resolution of the detector. The temperature-mobility calibrating curve comes out to be close to the already known [1],[2] dependence.

2. CALIBRATION BY CHARGE INJECTION

The STAR 1 detectors have built into them a method for self calibration. Between cathode strips 330 and 331 there is a charge injection port as shown in figure 1. By pulsing this pad we can inject charge in the silicon wafer and then measure the time **t** it takes for the signal to appear on the oscilloscope screen. The actual time $\mathbf{t_{drift}}$ it takes the charge to reach the anodes is a portion of this measured time: $t=t_{drift}+ t_o$, t_o is a measural offset constant called the start time. A typical pulse of 10 volts amplitude and 50ns full width at half maximum (FWHM) applied to the charge injection pads, gives an anode signal of 0.58 volts and 1.36 μs FWHM when the applied electric field is 250 V/cm.

The mobility μ is defined by the relation $\mathbf{V_{drift}} = \mu E$ where E is the electric field and v_{drift} the drift velocity. Since $\mathbf{V_{drift}=xt_{drift}}$, we can get the following expression for the mobility: μ = **x/tE** where **x** is the drift distance and **t** the drift time. It is now possible to calculate the mobility value for the SDD#416 without considering its temperature dependence, by measuring the drift time **t** for various voltages and constant drift distance **x**. To achieve this we inject charge in the Si wafer between pad#330 and 331. Knowing the distance of this point from the anode (x=330.5 x l20 μm), we measure the drift time for various voltages. The electric field **E=**(applied voltage - anode voltage)/(total drift distance) where the total drift distance is (33lxl20=) 3.972 cm. The results of these measurements are presented in figure 2.

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*University of Texas at Austin

**Lawrence Berkeley Laboratory

In this graph the slope m2 = $x/\mu E$, gives μ = 1378.08 cm^2/Vs. One also has to notice the **y** intercept that corresponds to the electronic delay time (t_o = 0.482 μs). The uncertainty in the drift time is 0.2% that is the ability of the experimentalist to read from the oscilloscope. The uncertainty in voltage is taken 0.5% and represents the electrometer reading ability. Later in this report we will study the dependence of the calibrating pulse with temperature.

3. TEMPERATURE STABILITY MEASUREMENTS

Thermistors were thought to be the most appropriate and cheapest method for temperature measurements. Other methods based on infrared thermometry (for example, use of an infrared camera) were rejected due to high reflectivity of the wafer surface. A test we did here in LBL confirmed this argument.

The YSI 44201 thermistor is used and is set at the "hottest point" on the wafer which corresponds to (0,0) point (see figure 3). In order to install the thermistor permanently on the wafer, we glue it on the surface. To do this we use a small ceramic tube (Al_2O_3) that is Electrically non-conductive and thermally highly conductive (38.9 W/m°K) and glue the tube on the wafer using a thermal insulating glue. Inside the tube we place the thermistor and glue it at the top, achieving in that way a good contact between the thermistor head and the wafer surface (see figure 4). The absolute uncertainty of YSI-44201 is 0.15 °C without software correction but the stability is less than 0.05 °C. The detector is cooled by dry Nitrogen of flow 200 cc/min.

The resistors shown in figure 4, transform the logarithmic relation between the resistance and the temperature to a linear one. In this way this linear relation is

$$R = (-17.115)T + 2768.23 \text{ Ohms}$$

where T is in °C. To record the output resistance we use a programmable electrometer in which we store the data per selected time intervals.

Using the method described above we first measure the temperature as a function of the applied electric field, and check the contribution of cooling. To do this we plot the temperature difference between cooling and no-cooling as a function of applied voltage. The results are shown in figure 5. One can see that for low voltages, cooling makes no big difference to the detector operation. As we go to higher voltages the temperature difference becomes very big and at 2000 volts we see a ΔT= 14°C. Consequently cooling prevents the detector from overheating in high applied electric fields.

Secondly, we test the temperature stability with and without cooling for the 261 detector. The results for various bias voltages for the no-cooling case are presented in figure 6. The temperature stability for 1500 Volts , with cooling is shown in figure 7. One can notice the difference in absolute temperature between cooling and no-cooling for the 1500 volts curve and that with cooling the absolute temperature is much lower. It is also obvious that cooling drives the detector to thermal equilibrium much faster. It assures very good temperature stability. One can clearly see the cooling effect in figure 8 where the relative spreads in the temperature distributions are presented for the two different situations (cooling no-cooling).

4. TEMPERATURE MEASUREMENTS ON SDD #416

In order to measure the temperature on 416 a different method has been adapted. An adjustable probe is used to allow us to measure at different points on the silicon wafer. The thermistor is carefully glued at the edge of the probe and the whole apparatus (detector -

probe) is kept fixed during probe adjustments and measurements. The position of the probe can be adjusted by adjusting screws that move it in the three space directions (figure 9). The ceramic tube is now attached at the top of the thermistor head allowing it to touch the surface.

Measurements are done under darkness and the whole apparatus is covered to prevent from temperature fluctuations caused by air-current flow inside the room. The absolute temperature measured is strongly affected by the room temperature and this factor has to be taken into account during slow measurements. In order to compare with the corresponding temperature differences for the SDD #261 between cooling and no-cooling, we take similar measurements on SDD #416. The absolute temperature difference for various applied voltages between cooling and no-cooling is presented in the following table.

Applied Voltage	Resistance difference	Temperature difference
2300 Volts	22 Ohms	13.34 °C
2000 Volts	19 Ohms	11.02 °C
1500 Volts	14 Ohms	8.12 °C
1000 Volts	9 Ohms	5.22 °C

If one compares with the values given in figure 5, it is clear that for high voltages (see 2000 volts) the 416 gives a smaller temperature difference of about 3 °C.

The relative temperature between two points on the silicon wafer is always constant during thermal equilibrium. In figures 10 and 11 one can see the relative temperature distributions with and without cooling. The temperature difference given in these graphs is relative to the lowest absolute temperature in degrees °C (or °K). A first observation from these two graphs is that there is an almost linear temperature gradient of the order of 0.3 °C along the drift direction (**Y**-direction) for the no-cooling case and a corresponding gradient of 0. 12 °C for the cooling case. Another result is the quadratic change along the **X** direction in both cases together with an almost perfect symmetry around **x**=15 mm. This symmetric behavior is expected because heat sources, like resistors, are mounted very close to the boundary of the trapezoid frame. It seems that closer to the anodes (large **Y**) this symmetry does not exist because of the relatively high temperatures for large **X**. This is caused by the fact that only the right side anodes are operating and hence they heat up the surrounding region. From the above one can infer that a design based on a rectangular frame could possibly give a better temperature distribution along the drift direction eliminating the linear gradient. Finally the error in measuring these temperatures is ±0.058 °C.

5. THE MOBILITY TEMPERATURE DEPENDENCE

Throughout the mobility calculation we did not consider any temperature dependence. In reality mobility depends on temperature and curves that describe this dependence for n-type silicon are given in the literature [1], [2]. For temperatures higher than 100 °K this relation is $\mu = AT^{\alpha}$ where the best fitting parameters for the constants A and α are $A=2.49\times10^{9}$ and $\alpha = -2.42$ for n-type silicon.

In our case, as we already know, the temperature on the silicon wafer depends on the applied electric field and hence the mobility is different for each applied voltage. The change in the mobility caused by temperature changes the estimated drift distance and particularly gives an extra uncertainty to its value. Consequently the SDD position resolution is highly dependent on the temperature distribution. We can find this mobility behavior using the charge injection method of chapter 2 and measuring at the same time the temperature and the delay time in the oscilloscope for various voltages. There is a good method for controlling the temperature on the SDD and this is the control of the cooling system. Hence we can turn on and off the cooling gas flow and measure the delay time as a function of temperature which we measure at the same time. The mobility for an applied voltage of 2000 Volts is presented in figure 12. From this graph one can see that a change in temperature of 0.6°K corresponds to a change in the mobility of $\Delta\mu$ =12 cm^2/Vs. We can calculate from this the drift distance uncertainty $\Delta \mathbf{x}$ using the relations $\mathbf{V_{drift}=xt_{drift}}$ and $\mathbf{V_{drift}} = \mu E$ where $E \approx 500$ volts/cm, $t_{drift} \approx 6.4$ μsec. This comes out to be

$$\Delta x \approx 380\ \mu m$$

for a drift distance of the entire detector. This result clearly shows that if temperature dependence is ignored, then for the SDD #416 at 2000 volts and with cooling where we have a temperature gradient of 0.12 °K, the position uncertainty will be **$\Delta x = 77\ \mu m$**. This fact makes the temperature calibration necessary.

The above measurements have been taken during the period of 3 minutes and the uncertainty for the mobility is 0.2% that is the error of measuring the time in the scope. There is also an uncertainty in temperature of the order of 0.058°K that contains the error in measuring from the electrometer. The curve that perfectly fits our experimental data is drawn in figure 12 while in figure 13 we perform an one-parameter fit keeping $\alpha = -2.4$. From figure 12 we can see that $\alpha = -4.4$ and $A=10^{14}$. These values give a more rapid change to the mobility with temperature than the expected values (figure 13).

6. DISCUSSION

It is apparent from the results above that cooling improves the performance of the SDD for the following reasons. First, it gives better temperature stability in higher voltages eliminating the fluctuations observed in the non-cooling case, then it lowers the absolute temperature yielding higher mobilities at a fixed voltage and finally it lowers the temperature gradient observed along the drift direction (which is in the worst case **dT**=0.3 degrees) to about 0. 1 degrees difference.

The other important outcome is the necessity of temperature calibration using charge injection through an injection port in the detector. As we have already described, this calibration is possible when we know the temperature-mobility curve for various voltages. Our calculations based on results presented in this report, show that even a small fluctuation in temperature, (say 0.1°K) can decrease the position resolution of the detector ($\Delta x \approx 60\ \mu m$) when drifting over the entire detector. We also obtain a temperature-mobility calibrating curve that seems to be close to the experimental data. Our present set-up allows only one injection port and in order to reduce the uncertainty in obtaining the right calibrating curve, we have to use more than one injection points and make separate tests.

ACKNOWLEDGEMENTS

The authors would like to thank K.Wilson and R. Bellied for their comments and suggestions.

REFERENCES

[1] S.Roe et al, Nucl. Instr. and Meth. A310(1991) 192.
[2] C.Jacoboni et al, Solid State Electron. 20(1977) 77.

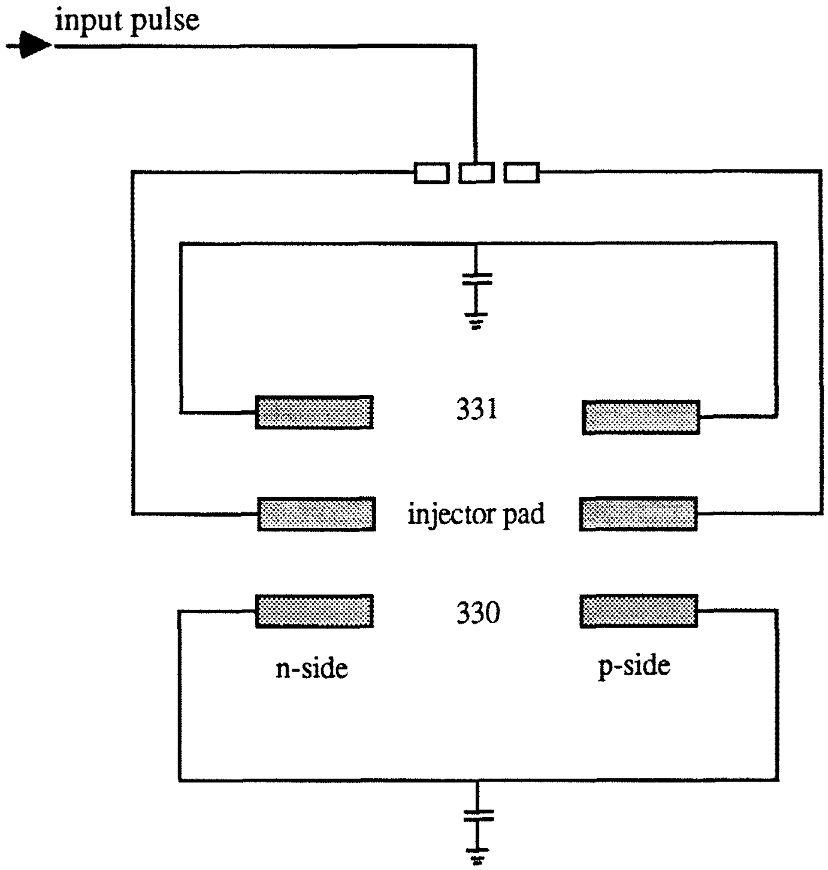

Figure 1: The STAR1 charge injection system.

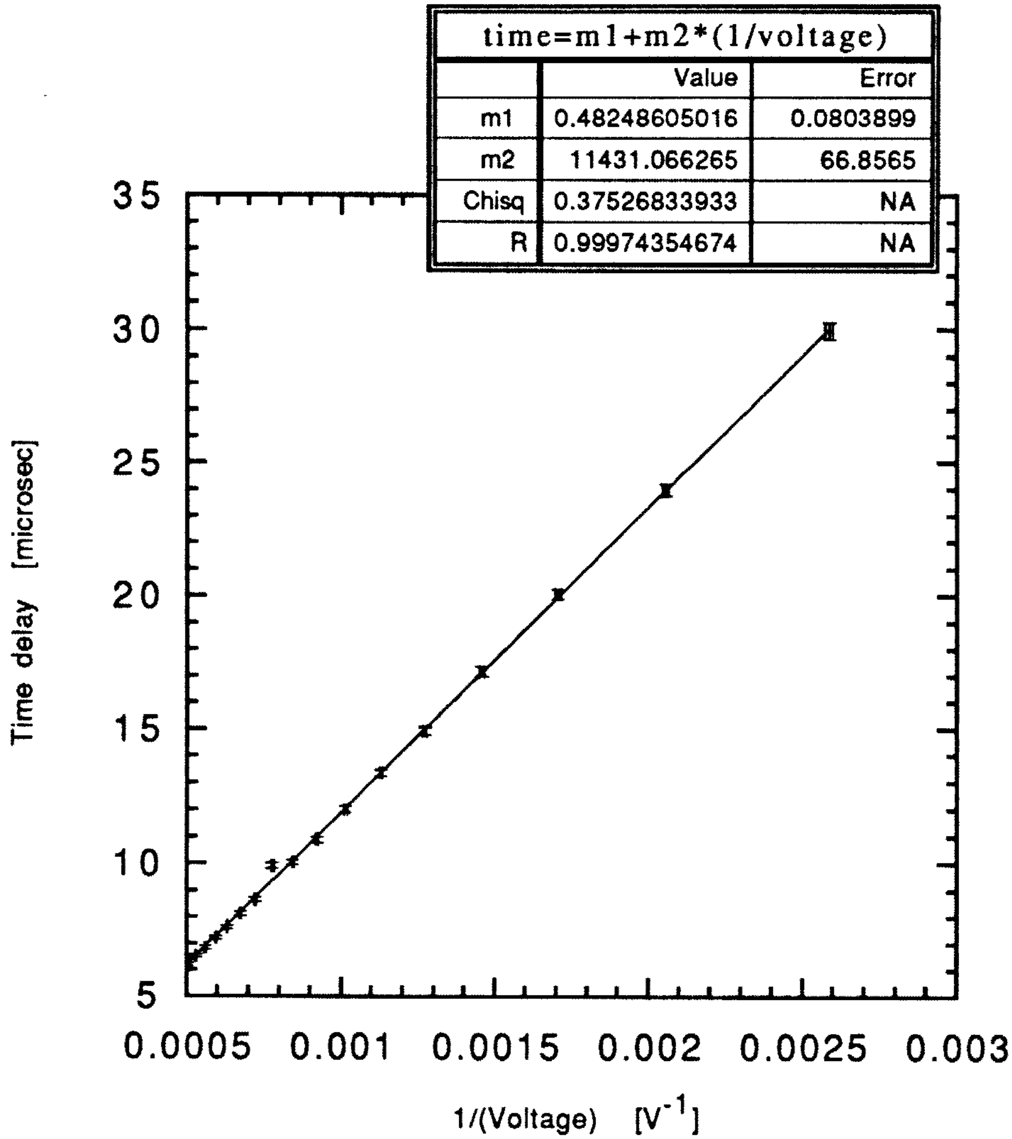

Figure 2: Drift time versus voltage^{-1} for various voltages.

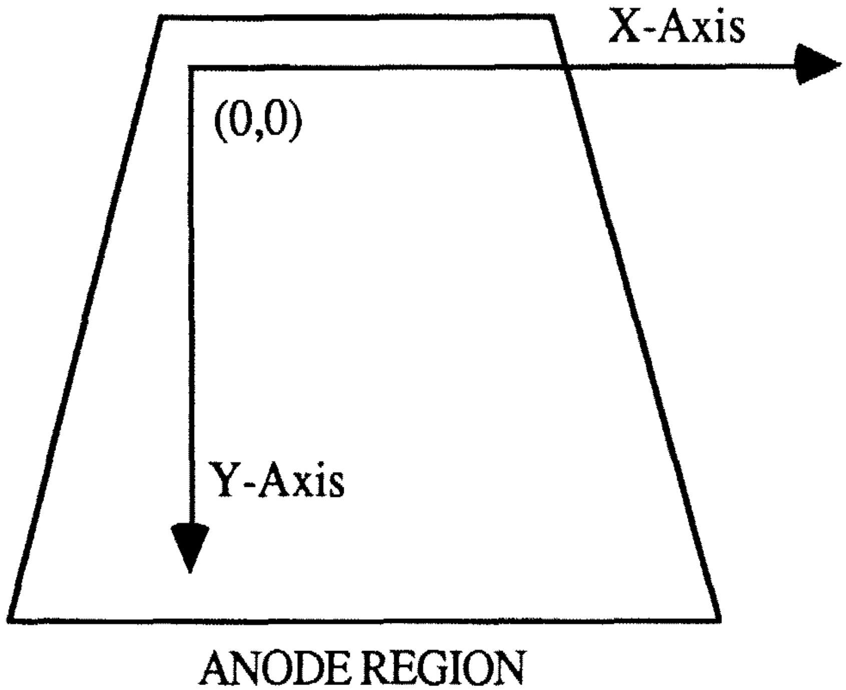

Figure 3: Coordinate system used on the Silicon wafer plane.

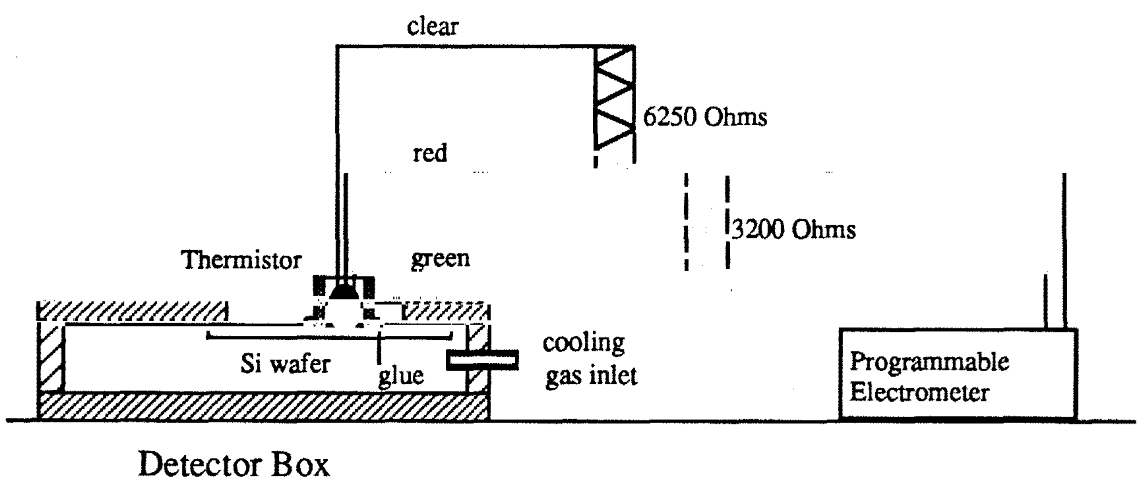

Figure 4: Experimental set-up for temperature stability measurements.

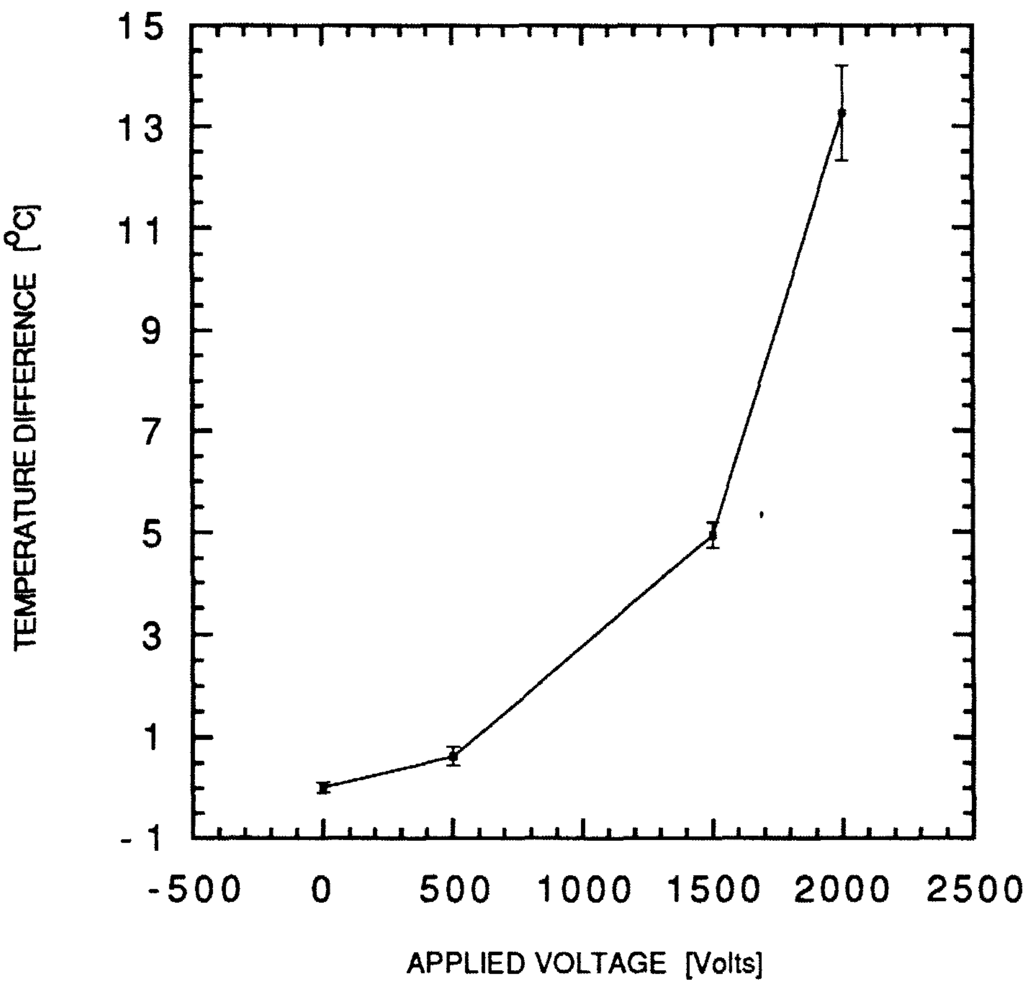

Figure 5: Absolute temperature difference between cooling and no-cooling for various voltages and for the SDD#261.

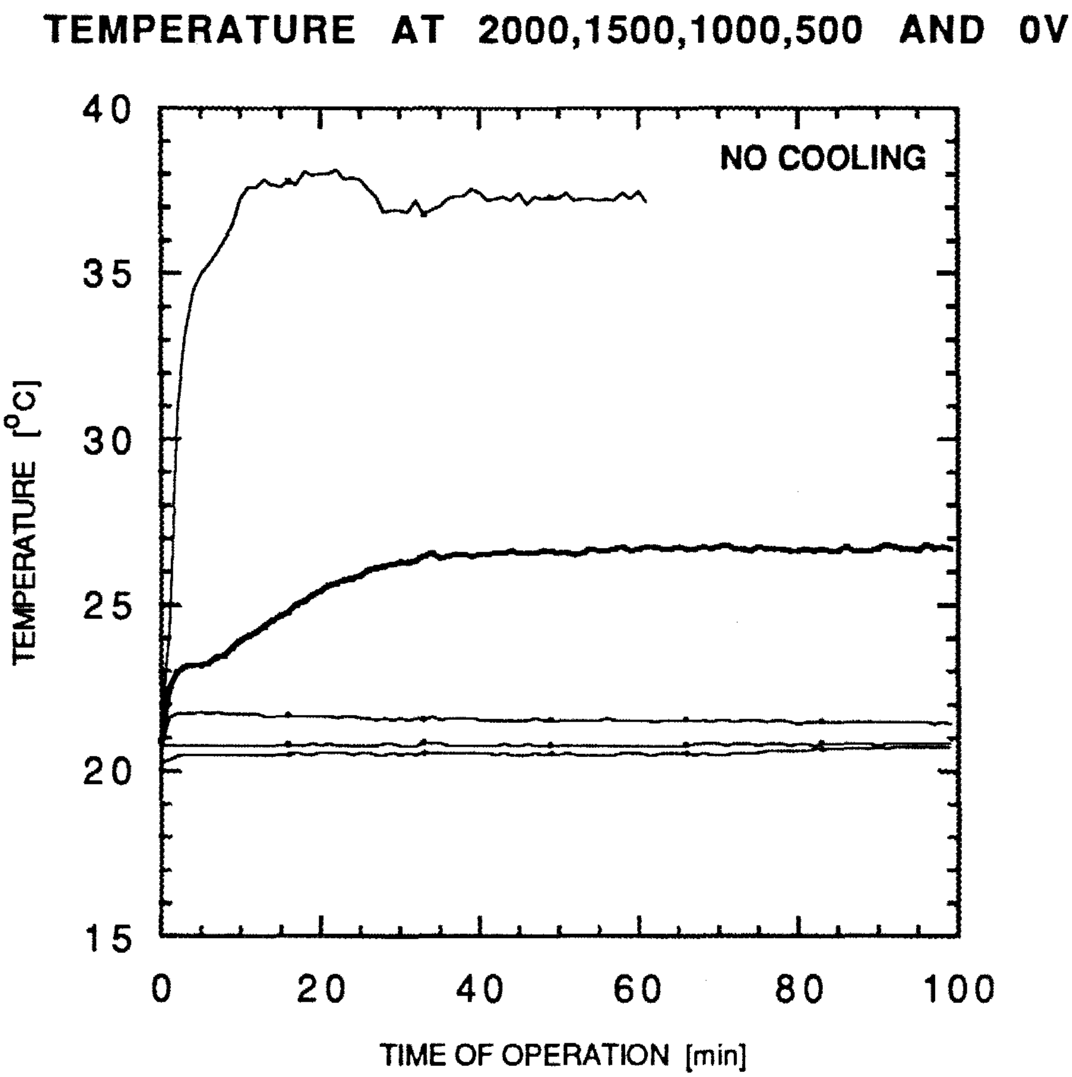

Figure 6: Temperature stability on 261 with no-cooling.

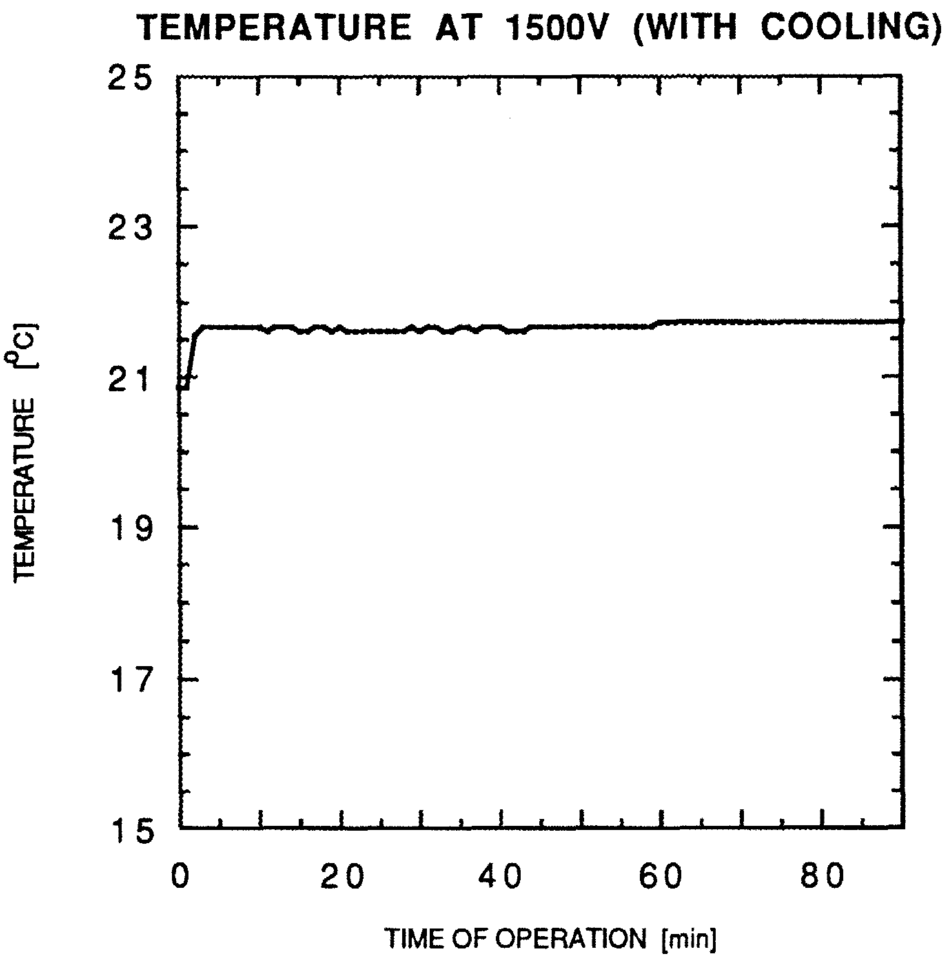

Figure 7: Temperature stability on 261 at 1500 Volts with cooling.

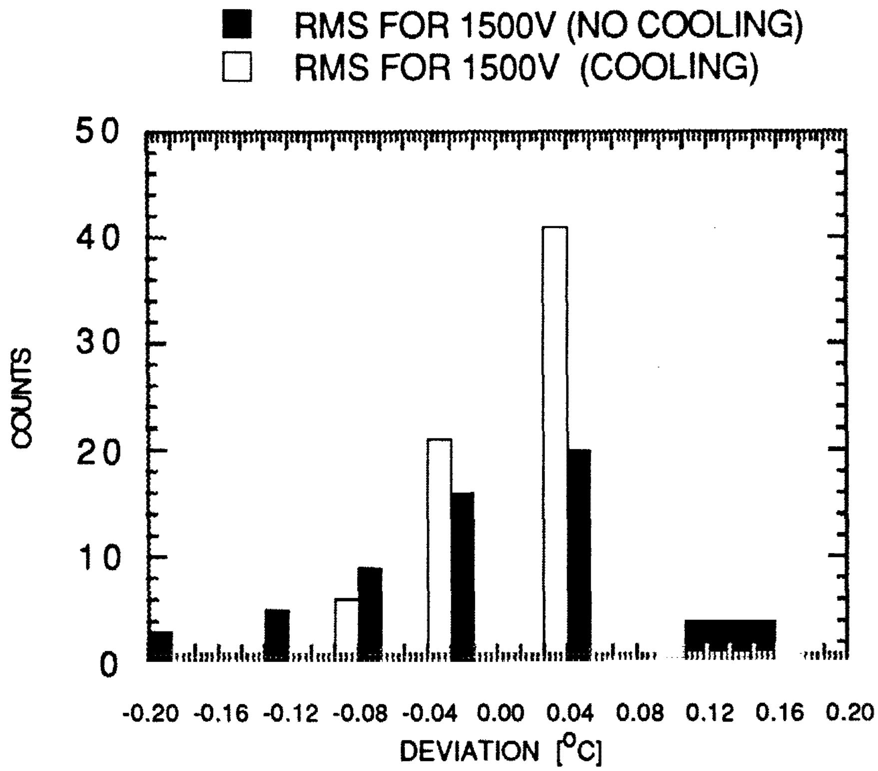

Figure 8: Temperature spread around the mean value for cooling and no-cooling at 1500 Volts.

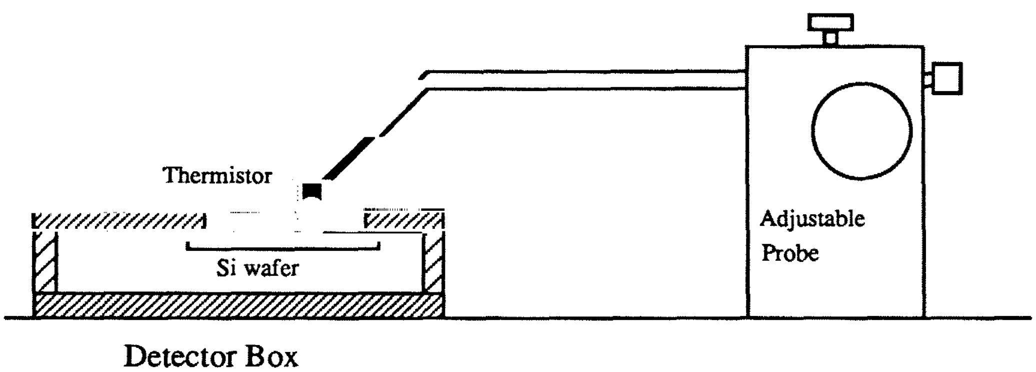

Figure 9: Experimental set-up for temperature measurements.

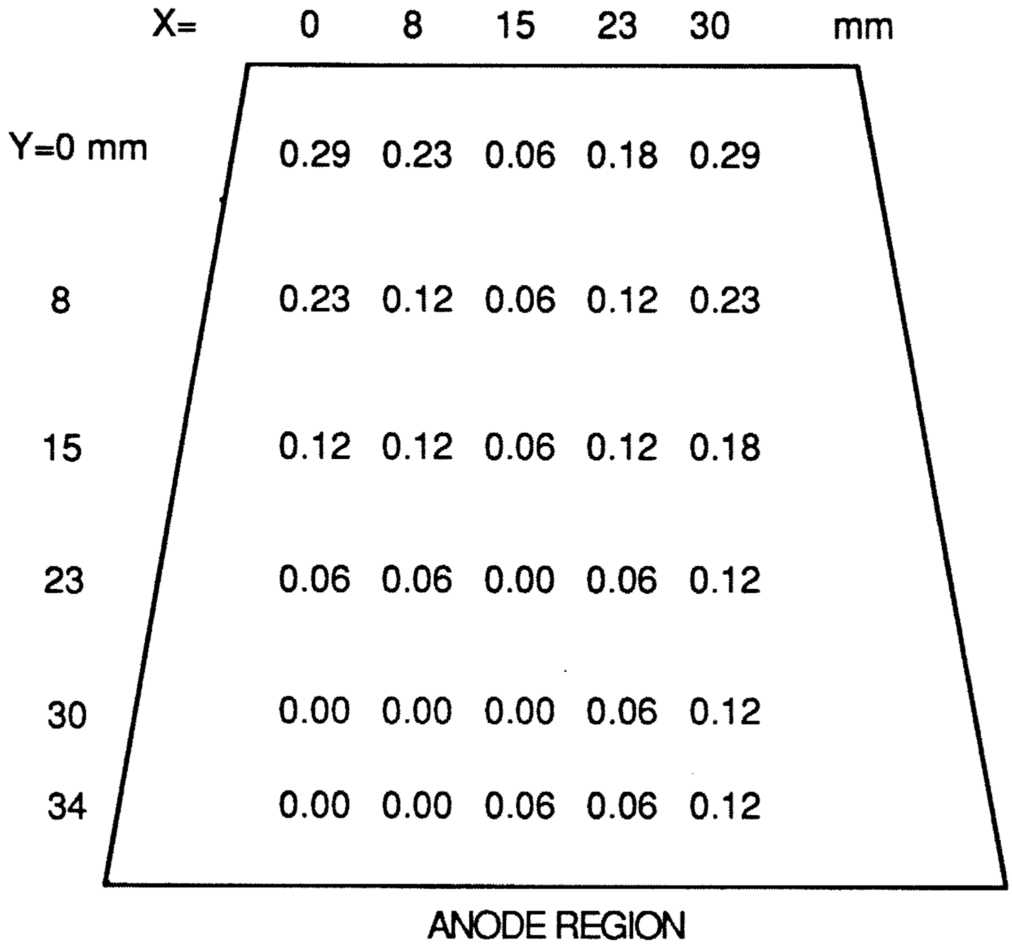

Figure 10: Temperature map on 416 with no cooling. Relative difference is shown with respect to the lowest temperature with uncertainty $\Delta T=\pm.058$ °C.

	X= 0	8	15	23	30 mm
Y=0 mm	0.12	0.06	0.06	0.06	0.12
8	0.06	0.06	0.00	0.06	0.06
15	0.06	0.06	0.00	0.06	0.06
23	0.06	0.00	0.00	0.00	0.06
30	0.00	0.00	0.00	0.00	0.00
34	0.00	0.00	0.06	0.06	0.06

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Figure 11: Temperature map on 416 with cooling. The uncertainty is $\Delta T = \pm 0.058$ °C.

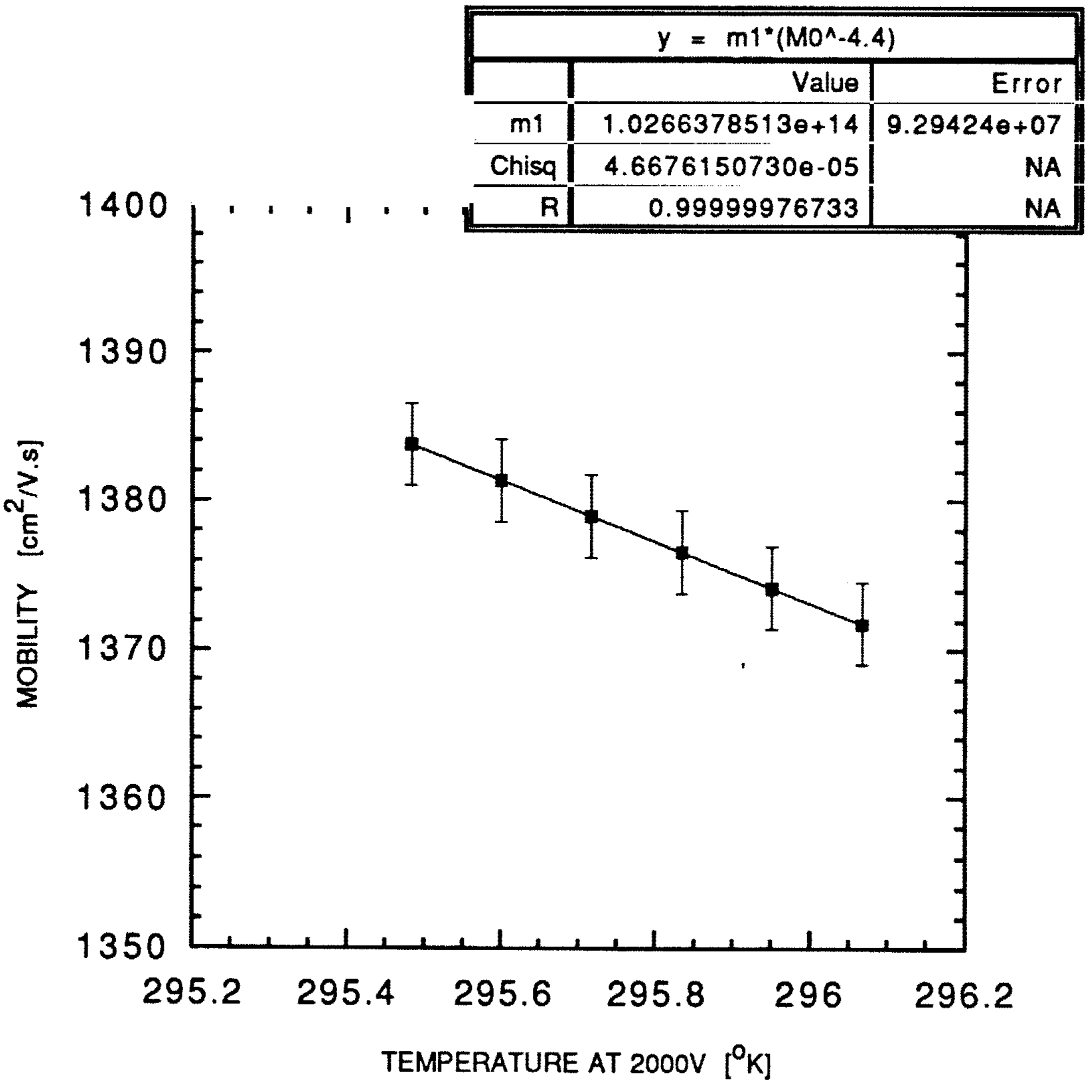

Figure 12: Mobility versus temperature at 2000 Volts applied voltage .

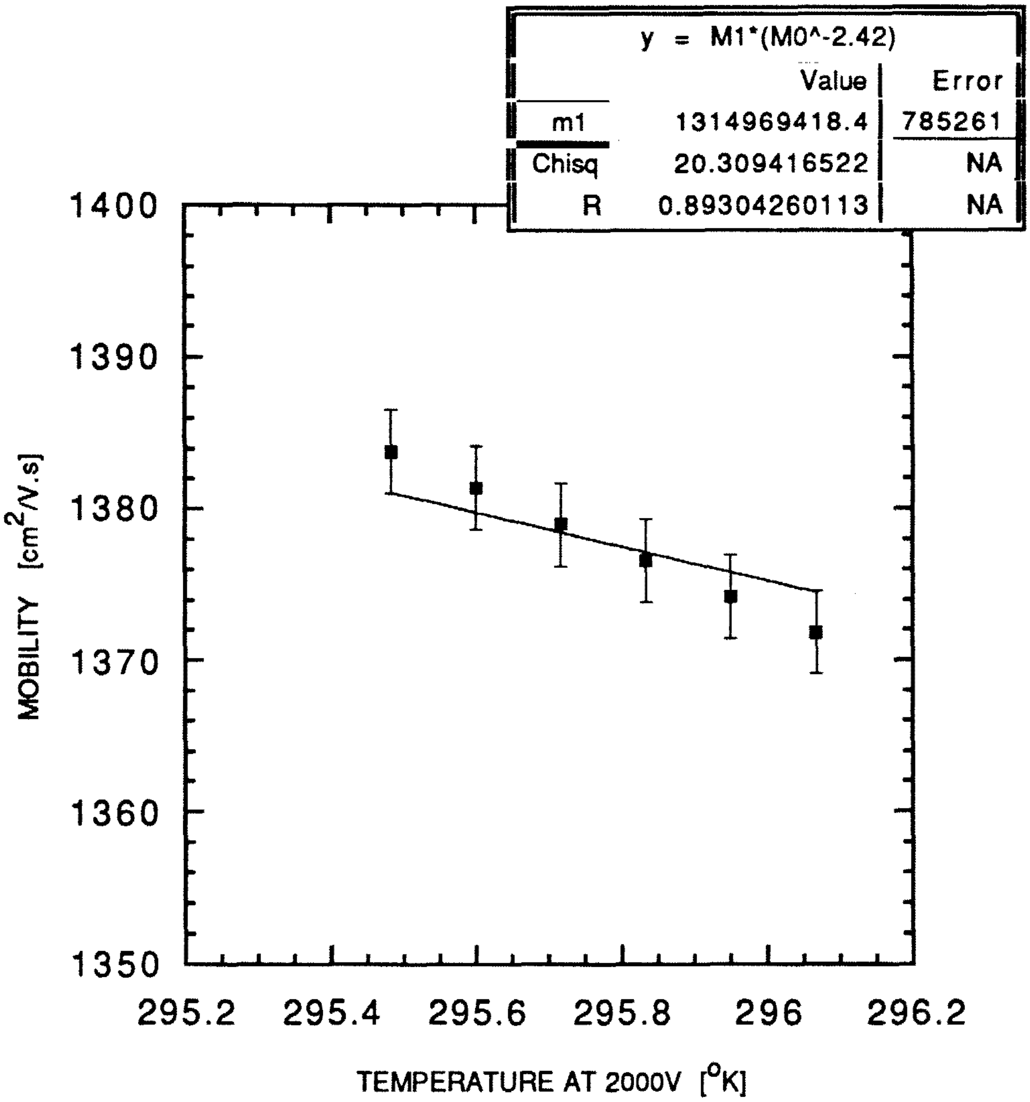

Figure 13: Mobility versus temperature at 2000 Volts applied voltage fitted with the expected curve.