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Summary of Results on Prototype Single-sided Silicon Microstrip Detectors for the DØ Barrel Tracker

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Abstract

This note describes the results of probe station measurements of electrical properties of silicon microstrip detector prototypes for the DØ barrel tracker layers 1 and 3. These single-sided detectors were fabricated at Micron Semiconductor. Two batches of detectors were fabricated with 5 detectors in each batch. We measured full depletion voltages, leakage currents, and properties of the polysilicon resistors and coupling capacitors. These properties were also studied as a function of radiation damage induced by a 500 MeV proton beam at TRIUMF.

1. Full depletion voltage

1.1 CV measurements on test structure diodes

One method to determine the detector full depletion voltage is to measure CV curves for a 1 cm^2 square diode test structure, which is present on every wafer processed by Micron. The three barrel detectors on each wafer are expected to have approximately the same full depletion voltage as the diode test structure on the same wafer. Small differences may arise due to thickness and resistivity variations across the wafer.

We measured the capacitance as a function of bias voltage at three frequencies, 1 kHz, 3 kHz and 10 kHz. Figure 1 shows the result of this measurement for wafer number 1265-15, which was from the first batch of prototypes. The estimated full depletion voltage is 10 V and agrees with measurement made by Micron who also quote 10 V. The full depletion voltage is much lower than our specification (35 V ± 15 V). This was explained by Micron by the fact that the resistivity of the silicon used for this batch of detectors was higher than that for the silicon they proposed to use for the final production detectors.

The second batch of detectors was produced using the silicon with lower resistivity, from the same crystal that will be used for the final DØ detectors. A test structure diode CV curve for a wafer from this batch is shown in Fig. 2. The full depletion voltage is approximately 40 V, which is within our specifications of 35 ± 15 V.

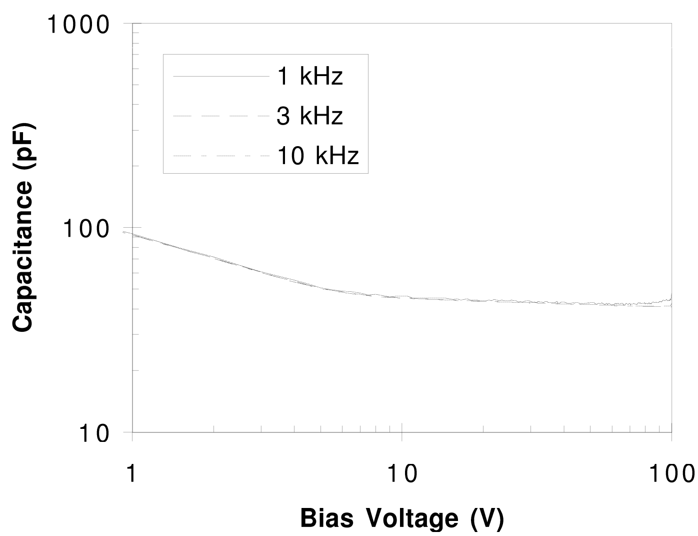

Fig. 1. CV curve for test structure diode on wafer 1265-15

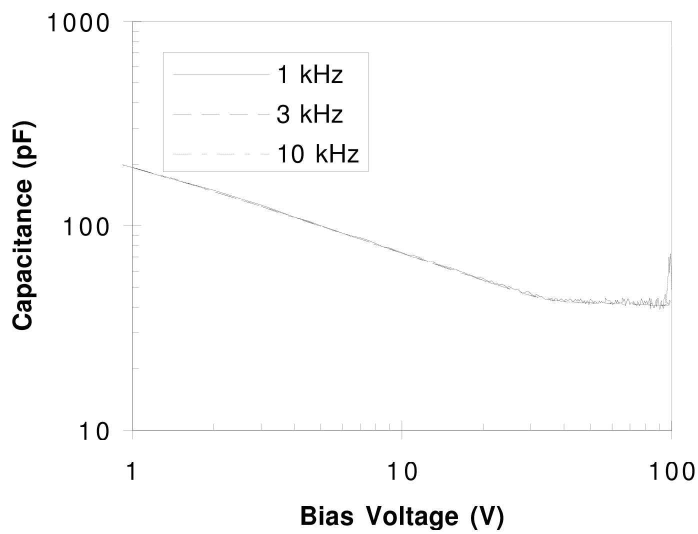

Fig. 2. CV curve for test structure diode on wafer 1135-16 (second batch).

1.2 CV measurements on test structure MOS devices

CV measurements were also carried out on the test structure MOS devices. Fig. 3. shows a typical CV curve. From the plot we see that the flat-band voltage (ΔV) is approximately 20 V. From this we can calculate the fixed oxide charge density

$$Q_f = \frac{C_{ox}\Delta V}{eA}$$

where Q_f is the number of fixed charges per cm^2, e is the electron charge, C_{ox} is the value of the capacitance below the flat band voltage and A is the area of the MOS capacitor. Using Cox = 838 pF, ΔV = 20 V and A = 0.25 cm^{-2} we obtain Q_f= 4.2×10^{11} cm^{-2}.

We believe that this oxide charge is responsible for a sudden drop in the measured detector CV characteristics at 20 V (see section 2.1).

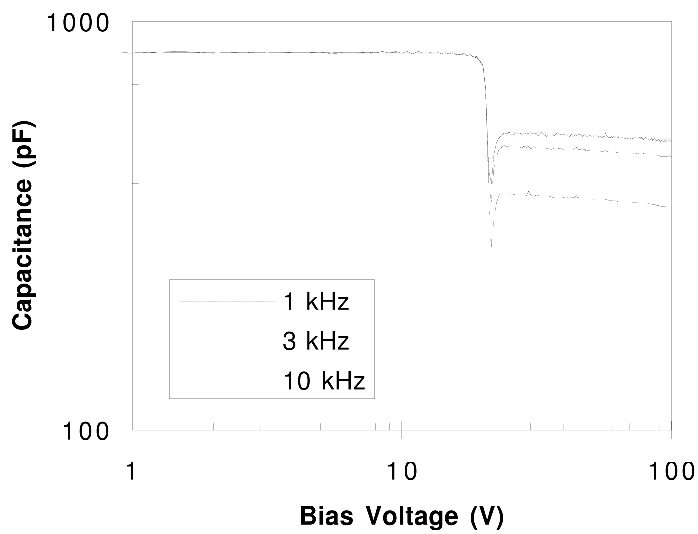

Fig. 3. Test structure MOS device CV characteristics for wafer 1135-16.

2. Measurements on detectors

2.1 CV measurements on detectors

We measured the CV characteristics of the barrel detectors by connecting between the bias line and the backplane. The effective capacitance depends on frequency because of the resistances of the polysilicon and the strip implantations. Fig. 4 shows a typical CV curve measured at f = 1, 3 and 10 kHz for a wafer from batch 1 (1265-15).

Note the sharp drop at about 20 V. This is believed to be due to the capacitance of an effective MOS device, formed by the oxide under the region of the detector containing the polysilicon resistors.

The true detector capacitance is the measured capacitance at low frequency (1 kHz) after full depletion, which is about 420 pF. This agrees with the theoretical value of

$$C = \frac{\varepsilon A}{d} = \frac{1.054 pF/cm \times 12.6 cm^2}{0.0303 cm} = 438 pF$$

Figure 5 shows a CV curve for detector 1135-16-A, which was from batch 2. Even after the sudden drop of capacitance due to the MOS effect at 20 V, the capacitance is still falling. The capacitance finally starts to become constant at around 45 V, showing that full depletion occurs at roughly this voltage. This is consistent with the full depletion voltage of 40 V, estimated from the test structure (Fig. 2).

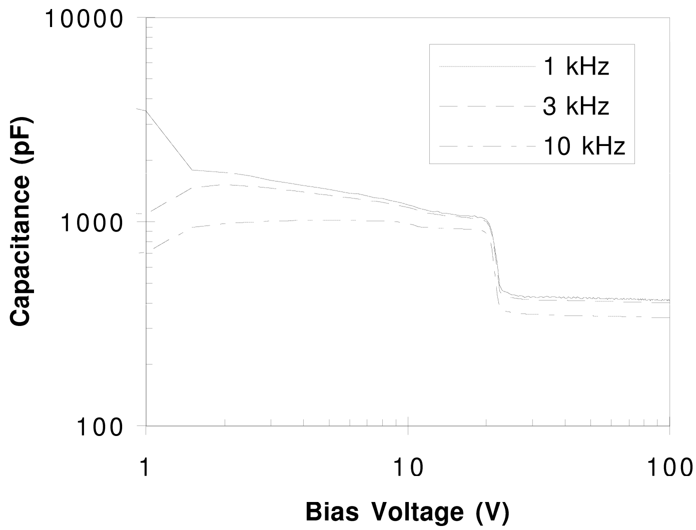

Fig. 4. CV characteristics for detector 1265-15-A (first batch).

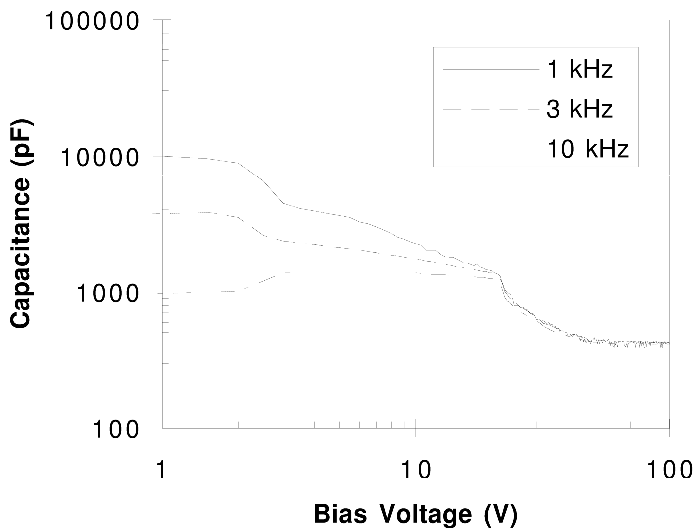

Fig. 5. CV characteristics for detector 1135-16-A (second batch).

2.2 Polysilicon Resistors

Measurements of the polysilicon resistance were made on the barrel detectors, with the detectors biased above full depletion. The resistance was constant over this range. A voltage was applied across the resistor and the current was measured. Fig. 6 shows IV curves measured at a bias voltage of 25 V for nine strips on detector 1265-15-B. Each curve is fit to a straight line to extract the resistance. The mean value of the resistance was (6.02 ± 0.02) MΩ. This agrees with Micron's measurements using the test structures.

In the second batch of detectors Micron were able to adjust the doping level of the polysilicon to reduce the resistance. Figure 7 shows the measured IV curve for a resistor on detector 1135-16-B. The resistance was 2.5 M Ω. This is to be compared with our specifications of (2.5 ±5) M Ω.

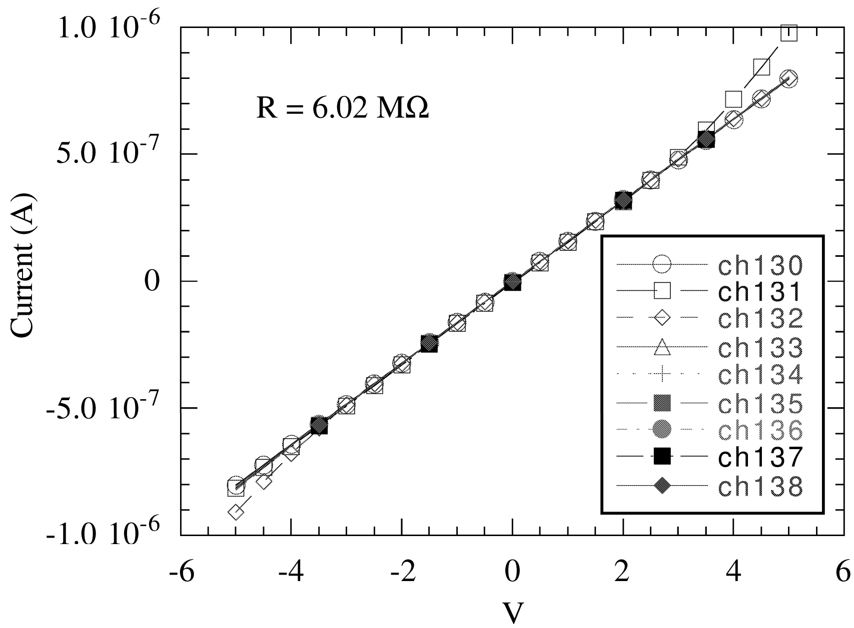

Fig. 6. Polysilicon resistor measurements, showing IV curves for polysilicon resistors from strip number 130 to 138, for detector 1265-15-B (first batch).

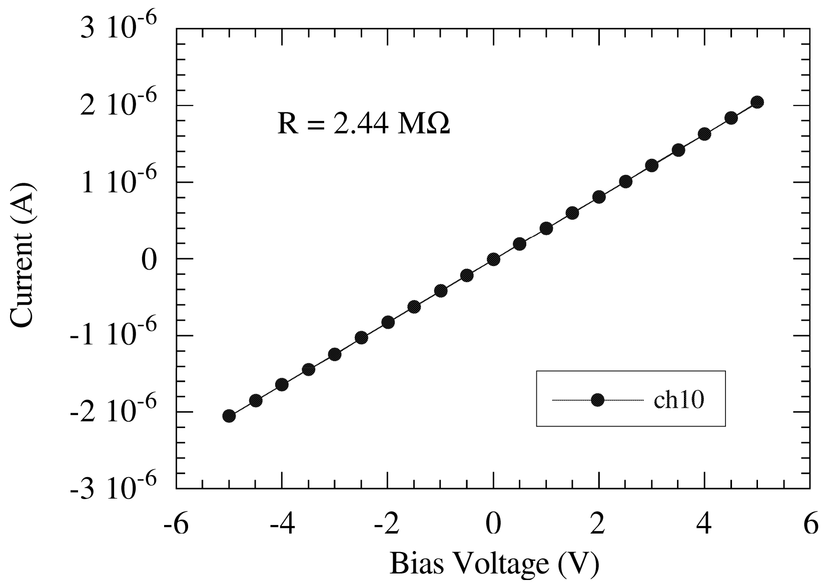

Fig. 7. Polysilicon resistor measurement for detector 1135-16-B (second batch).

2.3 Coupling Capacitance

The coupling capacitance was measured directly on the detectors, by connecting between the strip implant and the aluminum electrode. The effective capacitance drops off at high frequencies due to the finite strip implant resistance. Figure 8 shows the measured capacitance as a function of frequency for detectors 1135-16-A and 1135-18-A. The coupling capacitance is the value measured at low frequency where the effect of the strip implant impedance is negligible. The coupling capacitance measured was $114\ \mathrm{pF}$ for detector 1135-16-A corresponding to $19.7\ \mathrm{pF/cm}$. We note that the fall off at high frequency is less than for the F disk prototype detectors, indicating that the strip implant resistance is lower. This is expected since the strips are wider.

Table 1 summarizes the coupling capacitance measurements for four different detectors.

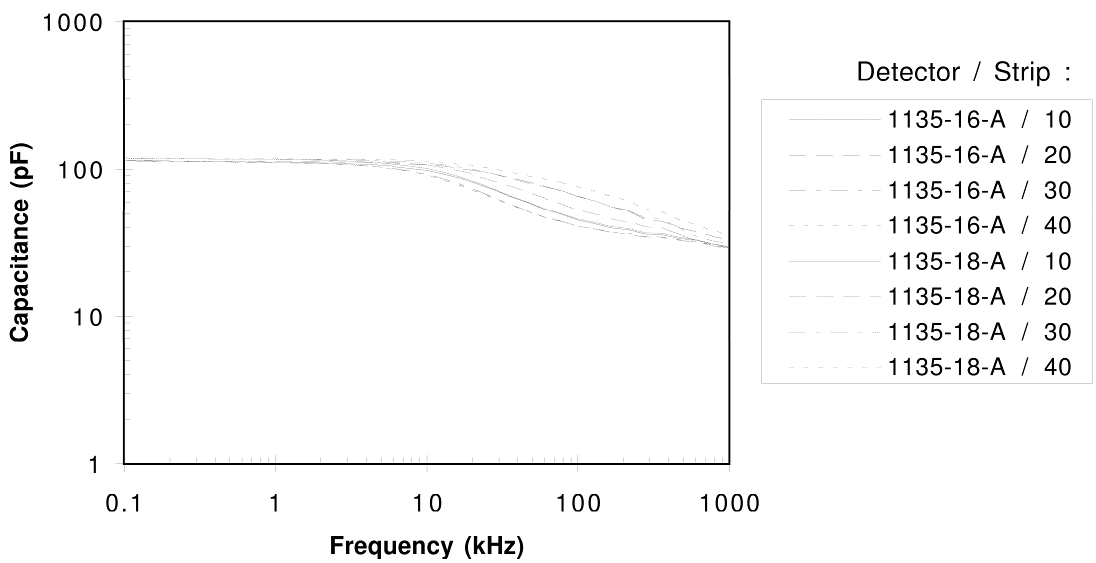

Fig. 8. Coupling capacitance measurement for two detectors from wafer 1135-16 (second batch).

Detector	Batch	Coupling Capacitance (pF)
1135-16-A	1	114
1135-18-B	1	119
1265-15-A	2	100
1265-15-B	2	102

Table. 1. Coupling capacitance values for different detectors.

2.4 Coupling Capacitor Breakdown Voltage

The breakdown voltage of the coupling capacitors on the detectors was measured by applying a voltage between the strip implant and the aluminum electrode. A current limit was set to avoid destruction of the detector. The applied voltage was increased from zero volts until the current exceeded 20 pA at which point the applied voltage ramp was reversed, going back down to 0 V. A typical measurement is shown in Fig. 9. A hysteresis effect is apparent, as was seen on the F disk prototypes. In all measurements the breakdown occurred at above 100 V.

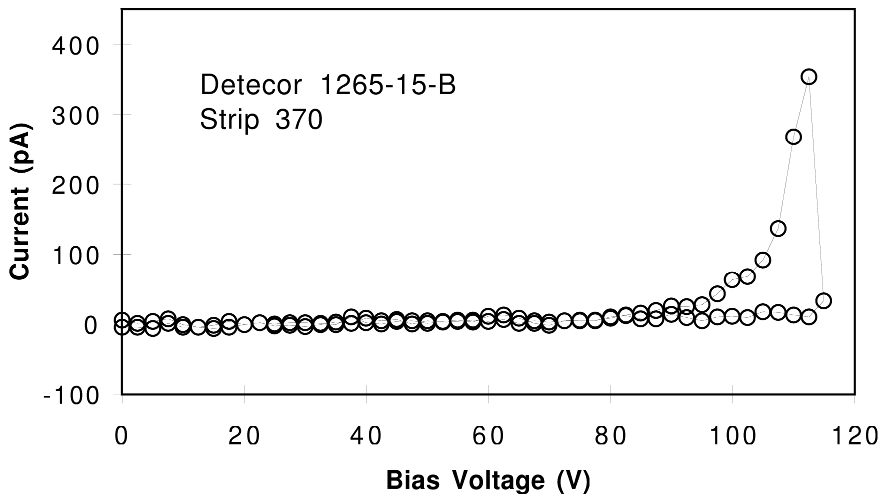

Fig. 9. Typical IV measurement for a coupling capacitor on detector 1265-15-B.

2.4 Coupling Capacitor Breakdown Voltage

To test for shorts through the coupling capacitor silicon dioxide dielectric, all strips on seven detectors have been measured. Results are given in appendix A and summarized in Table 2.

Detector	Batch	Number of Shorts (Measured at)
1265-15-A	1	9 (Micron) 10 (UCR – after irradiation)
1265-5-B	1	11 (Micron) 9 (FNAL – after irradiation)
1265-14-A	1	2 (Micron) 2 (UCR)
1135-16-A	2	2 (Micron) 7 (UCR)
1135-18-A	2	4 (Micron) 5 (UCR)
1135-18-A	2	1 (Micron) 7 (UCR)
1135-18-B	2	1 (Micron) 1 (UCR)

Table. 2. Coupling capacitor shorts measured on seven prototype detectors.

3. Radiation damage

3.1 Coupling capacitance

To test radiation damage effects on the detectors, some of the prototypes from the first batch were irradiated at TRIUMF using a 500 MeV proton beam. Probe station measurements were made before and after irradiation. Fig. 10 shows the effect of radiation on the capacitance of the coupling capacitors of detector 1265-15-A. The average dose was obtained from aluminum foil activation measurements and found to be 1.15 Mrad, with an estimated error of ≈20%. As can be seen this exposure to 1.15 Mrad of protons has no effect on the value of the true capacitance (low frequencies). However the effective capacitance starts to fall at about 10 Hz after irradtiation compared with approximately 100 kHz before irradiation. This indicates that the effective strip implantation sheet resistance has increased.

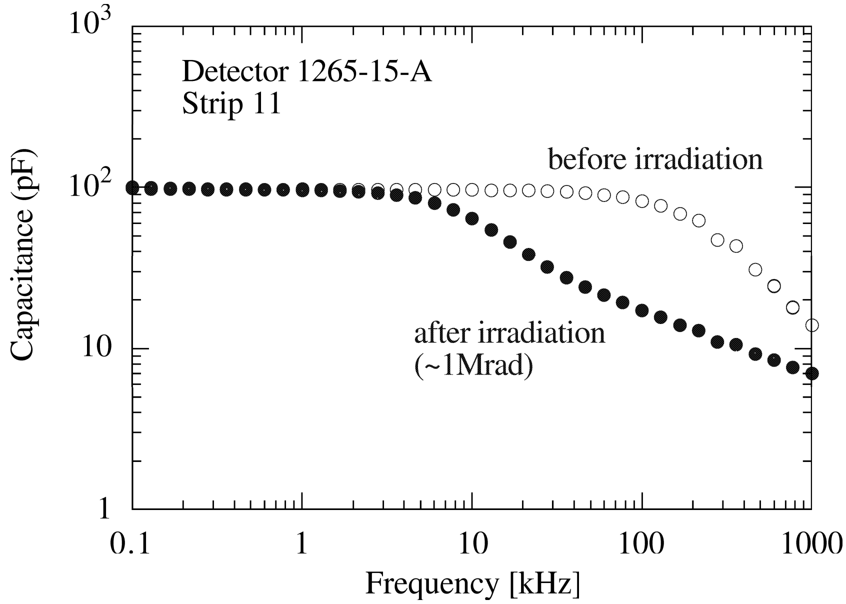

Fig. 10. Effect of 1.15 Mrad proton radiation on coupling capacitance for detector 1265-15-A.

3.2 Coupling capacitor short circuits

Coupling capacitors were measured for shorts between the aluminum strip and the p^+ implant before and after irradiation for two detectors from batch one. The results are summarized in Appendix A. Out of a total of 768 strips measured, shorts were found in only two strips which were not shorted before irradiation. However, it is not certain that these shorts were not caused by assembly and handling of the detectors.

3.3 Polysilicon resistors

The polysilicon resistance was measured before and after irradiation for detector 1265-15-A as shown in Fig. 11. The post radiation measurement is made in the presence of the strip leakage current which is approximately 0.5 μA. Fig. 11 shows the measured polysilicon resistance as a function of detector bias voltage. Above the full depletion voltage (≈50 V) the resistance obtained was approximately 5.5 MΩ, compared with 6.2 MΩ for the unirradiated detectors. This effect is not understood, but may be due to the influence of the leakage current or due to oxide charge effects below the polysilicon.

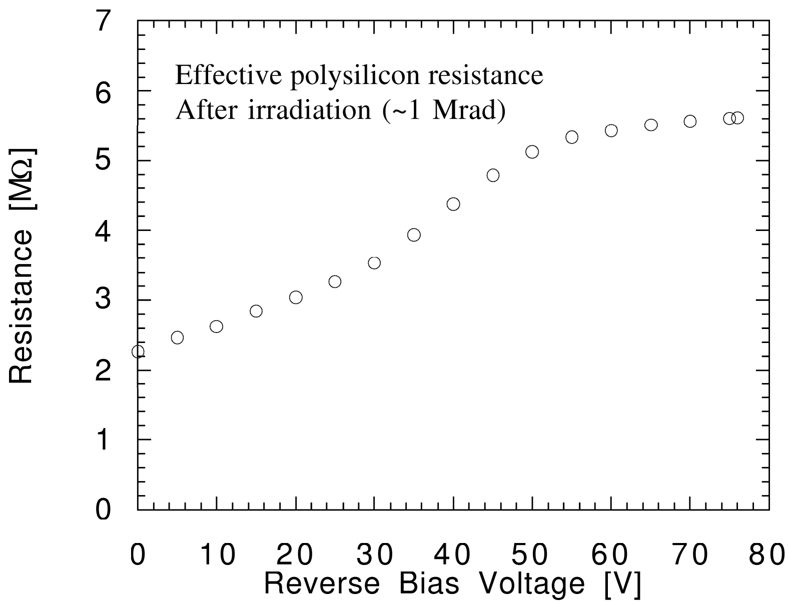

Fig. 11. Measured polysilicon resistance as a function of detector bias voltage for detector 1265-15-A after 1.15 Mrad proton irradiation.

4. Conclusions

We described probe station measurements made on two batches (5 detectors in each batch) of prototype detectors for the DØ Barrel Tracker layers 1 and 3. Leakage currents, full depletion voltages, polysilicon resistances and coupling capacitances were all found to be within specifications, as given in DØ note 2075. The fraction of strips in which the capacitor was found to be a short circuit was in the range 0.26%–2.86% (Micron measurements), 0.26%–2.34% (DØ measurements) for the seven detectors measured. Our specification of <0.5% is expected to be met for production detectors.

Finally, we exposed the Micron prototype detectors to 1.15 Mrad of 500 MeV proton irradiation. We found negligible change in the values of the polysilicon resistance and coupling capacitance and showed that out of a total of 768 strips measured, shorts were found in only two strips which were not shorted before irradiation. It is likely that these two shorts were due to handling rather than the effects of radiation damage.

the rate of radiation induced coupling capacitor shorts was <0.26%

Acknowledgments

The detector irradiation was carried out at TRIUMF experiment E-740, with the help of many people. We thank Dave Hutcheon, Stanley Yen and the TRIUMF staff. We also thank the E-740 experiment team: Mao-Tung Cheng, Sung Han, Kara Hoffman ,Yohse Iwata, Tacy Joffe-Minor, Shekhar Mishra, Ron Lipton, Lenny Speigel and Benn Tannenbaum. Finally, for their work on foil activation measurements, we thank Vernon Cupps and Steve Benesch of the Fermilab ES&H Section Activation Analysis Laboratory and David W. Vehar and Charles V. Holm of the Radiation Metrology Laboratory at Sandia National Laboratories.

Appendix A – Summary of Capacitor Shorts

Strip numbers of shorted coupling capacitors on the DØ 3-chip barrel prototypes
Measured by Micron (before shipping) and by DØ (place and person indicated)

1) Measurements on detectors irradiated at TRIUMF

Detector 1265-15-A

	Micron	*UCR - Boswell (after irradiation at TRIUMF)*	
		9	*Destroyed by measurement of breakdown vo*
	37	37	
	67	67	
	84	84	
	85	85	
	178	178	
	279	279	
		283	
	306	306	
	326		
	355	355	
Total:	9	10	
Total (%):	2.34	2.60	

Detector 1265-15-B

	Micron	*FNAL - Rapidis (after irradiation at TRIUMF)*	
	1	1	
	32		
	149		
	158	158	
	178	178	
		180	*Destroyed by wire-bonding?*
	190	190	
		201	*Destroyed by measurement of breakdown vo*
		202	
	262	262	
	281		
	296	296	
	325	325	
	368	368	
Total:	11	9	
Totsl (%):	2.86	2.34	

2) Measurements on unirradiated detectors

Detector 1265-14-A

	Micron	*UCR - Bischoff*
	71	71
	18	18
Total:	2	2
Total (%):	0.52	0.52

Detector 1135-16-A

	Micron	*UCR - BIschoff*
		74
	88	88
		170
		203
		211
		343
	377	377
Total:	2	7
Total (%):	0.52	1.82

Detector 1135-16-C

	Micron	*UCR - BIschoff*
		172
	181	
		252
	322	322
	352	352
	355	355
Total:	4	5
Total (%):	1.04	1.30

Detector 1135-18-A

	Micron	*UCR - BIschoff*
		14
		326
		374
		295
	365	365
		367
		383
Total:	1	7
Total (%):	0.26	1.82

Detector 1135-18-B

	Micron	*UCR - BIschoff*
	102	102
Total:	1	1
Total (%):	0.26	0.26