Version 2/ 11.02.2010

Punch-through location in the SCT sensors

A.Chilingarov, Lancaster University

The SCT sensors have punch-through protection (PTP) gaps at both edges of the implant strips. However these gaps are different. According to Hamamatsu (thanks to Nobu Unno for providing this information) at the edge opposite to the bias resistors (far side) the gap width is 8 μm while at the resistor (near) side it is 30 μm. The photographs made recently by Bart Hommels confirm this strong asymmetry.

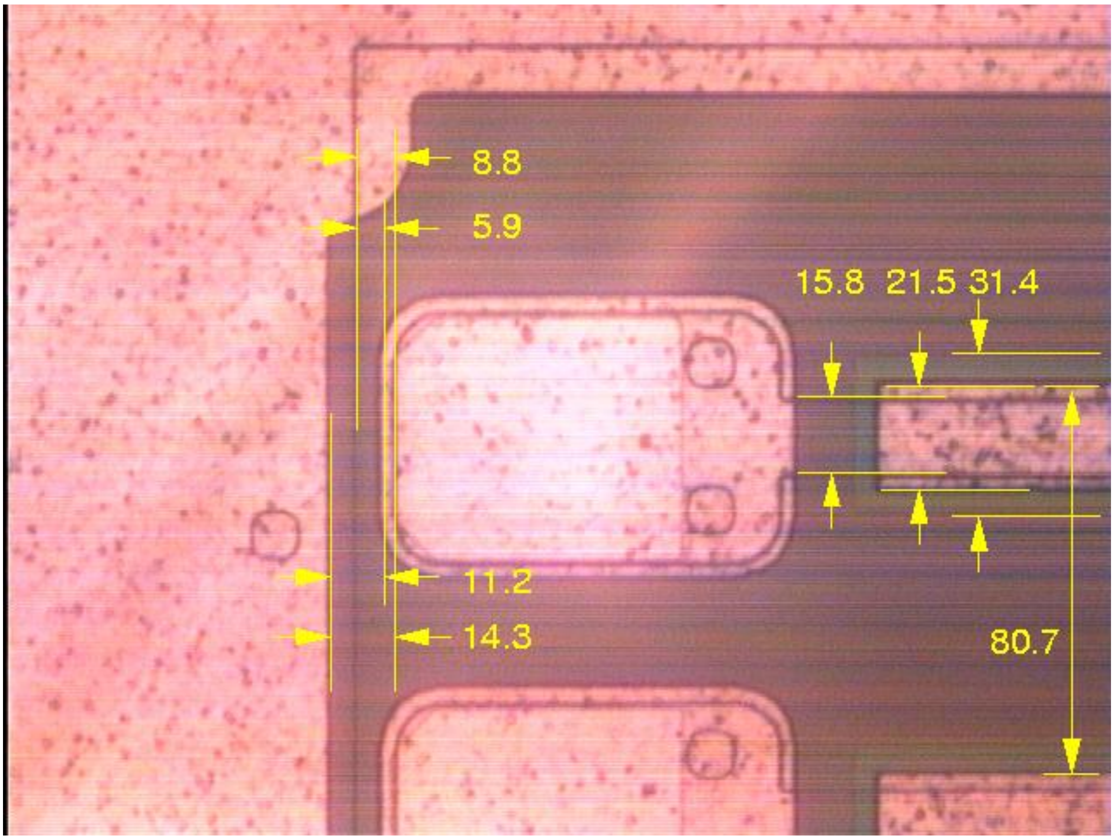

Photo 1. Barrel sensor, far side. The dimensions are in micrometers.

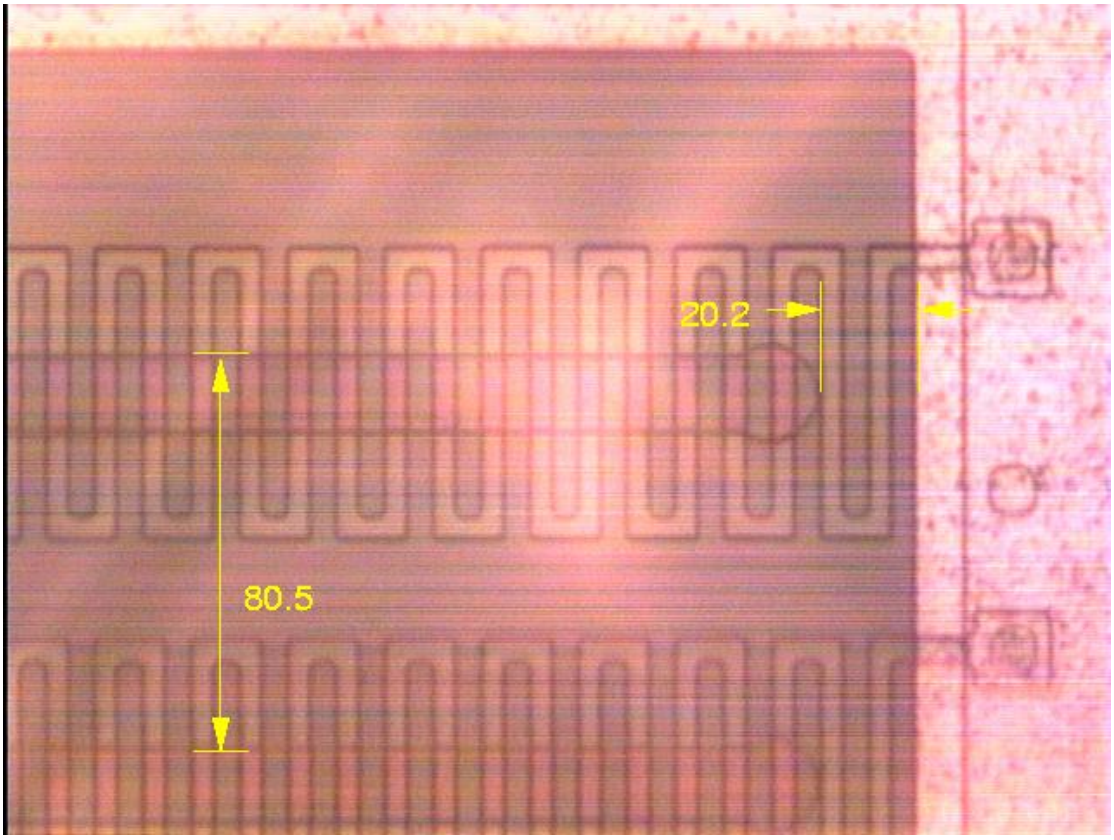

Photo 2. Barrel sensor, near side.

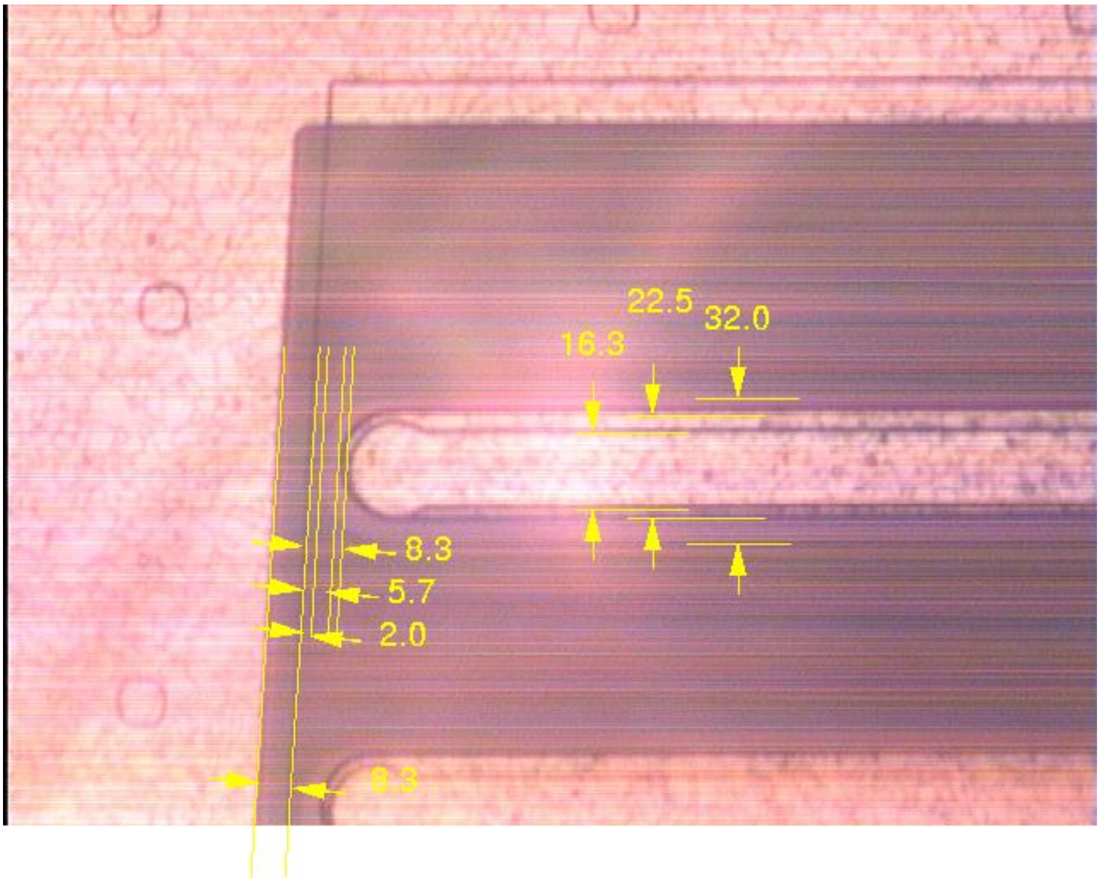

Photo 3. End-cap sensor, far side

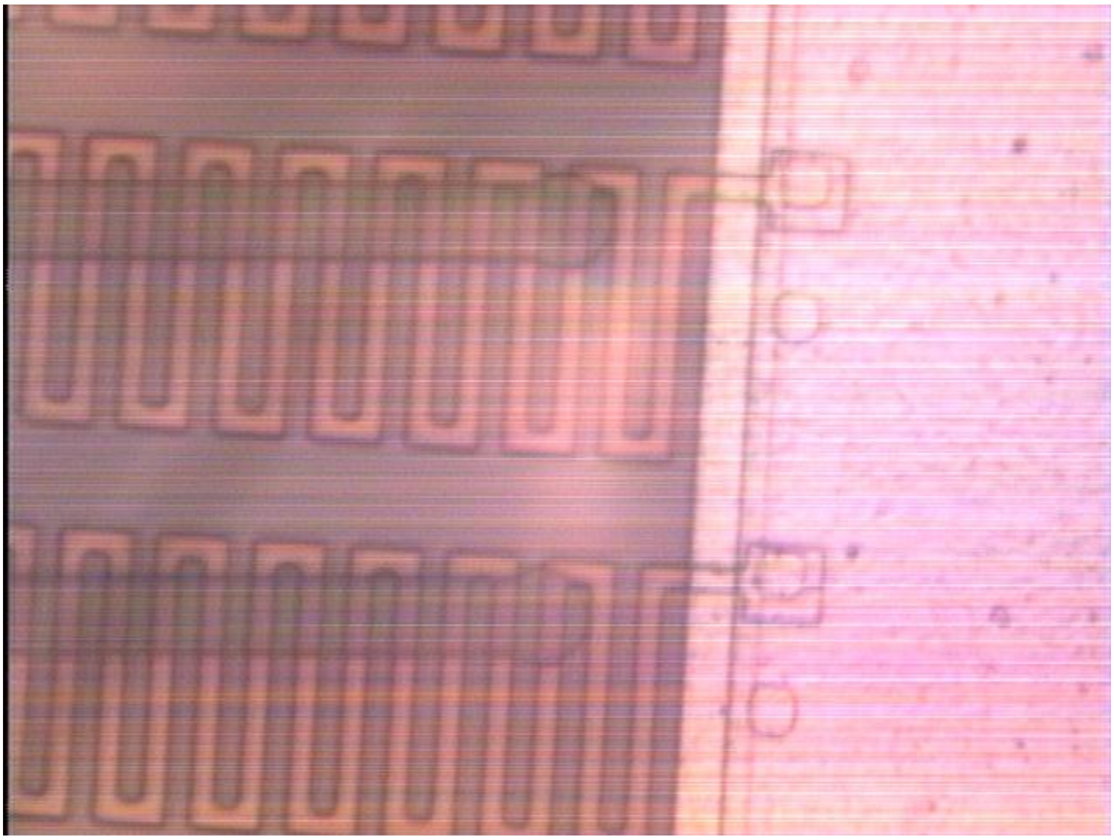

Photo 4. End-cap sensor, near side

Basing on this information it was usually assumed that the PT should develop mainly at the far edge of the strip. If the test potential is applied at the near edge (for the end-cap sensors this is the only option since no implant contact pad is available at the far side of the strip) then the maximum current, which can be drained via the PTP gap, should be limited by the implant strip resistance R_{st}. The implant resistivity is specified to be <200 kΩ/cm and according to Nobu Unno's information received from Hamamatsu is typically ~80 kΩ/cm. For 6cm long strip it implies R_{st} ~500 kΩ. However the minimum resistivity observed in measurements with many end-cap sensors is always significantly lower than this value. In Fig.1 below it is typically <40kΩ and doesn't show any sign of saturation. Note that the value for $R_{bias}||R_{st}$ of ~350 kΩ, which should limit the total resistivity if the PT develops at the far side only, is passed at the voltage not much higher than the PT onset voltage. These contradictions initiated recently a dedicated investigation of the PT location.

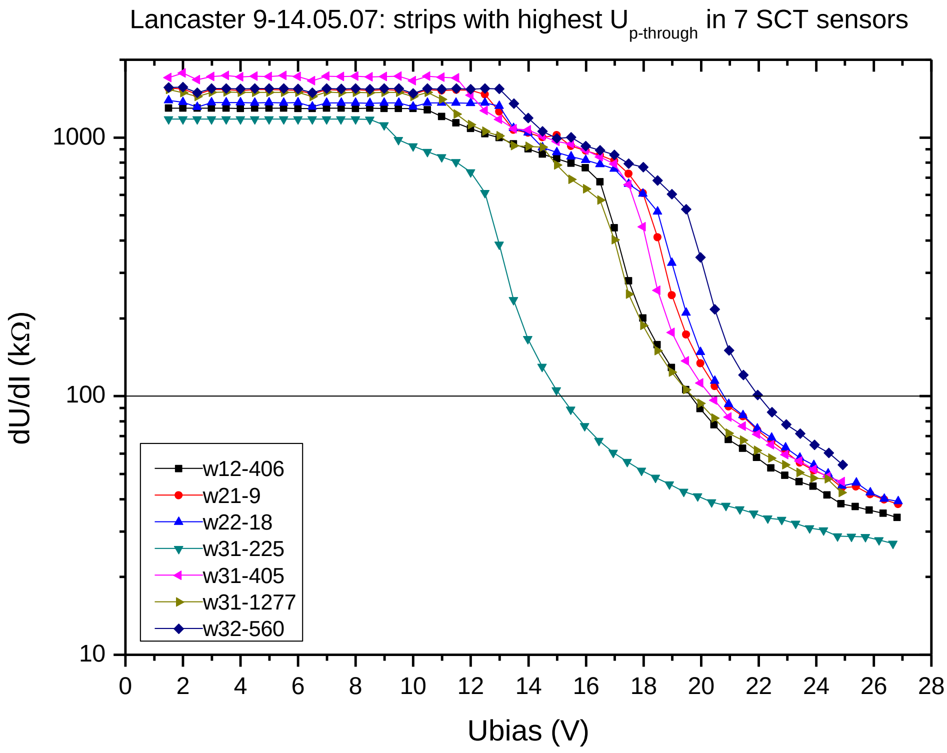

Fig.1. PT in 7 different end-cap sensors soon after application of 100V bias.

The measurements reported here were performed with barrel sensor B-4098 (thanks to Bart Hommels for sending me two barrel sensors for these tests). As can be seen on Photo 1 the barrel sensors have the implant access pad at the far side of the strip as well. This allowed a study of the PT development for each strip side separately. For this purpose the test potential was applied at one edge of the implant while the opposite edge was connected to the ground (as well as the bias rail). For completeness the usual type of measurements (without grounding of the opposite strip edge) were also made. The main results are presented in the plots below. To allow a good stabilisation the sensor was kept biased for 67 hours before these measurements were performed.

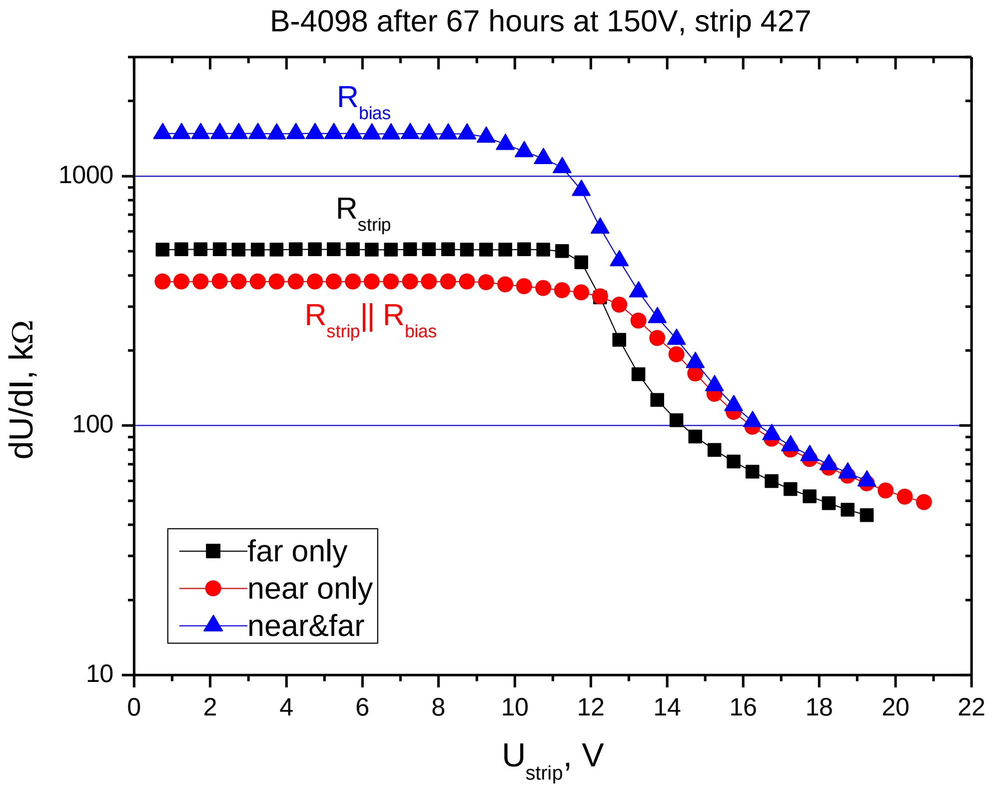

Fig.2. Differential resistivity in different test configurations.

For the test voltage applied at the far side with the near side grounded (denoted in the plots as “far only”) the initial plateau resistivity representing R_{st} is at the level of 507 kΩ in a perfect agreement with expectations. With the test voltage applied at the near side and the far side grounded (“near only” data) the plateau resistivity is 387 kΩ that is equal to R_{st} and R_{bias} in parallel. Clearly the PT develops at the near side as well. Finally when the test potential is applied at the near side with the far side ungrounded (“near&far” data) the plateau value of 1480 kΩ represents R_{bias} and for high potential values the resistivity approaches that for the near side only since the PT at the far side is effectively cut off by a large strip resistance.

In Fig.3 the punch-through current is shown for all 3 test configurations at the test potential values around the PT onsets. The PT current was calculated by subtracting an ohmic component $U/R_{plateau}$ from the total measured current. Interestingly for the near side alone the PT onset (~9.5V) is even lower than that for the far side alone

(~11.5V) in spite of the larger PTP gap at the near side. For the "near&far" configuration the PT current follows exactly the pattern of the "near only" current up to 11.5V where an additional component due to the PT current at the far side appears.

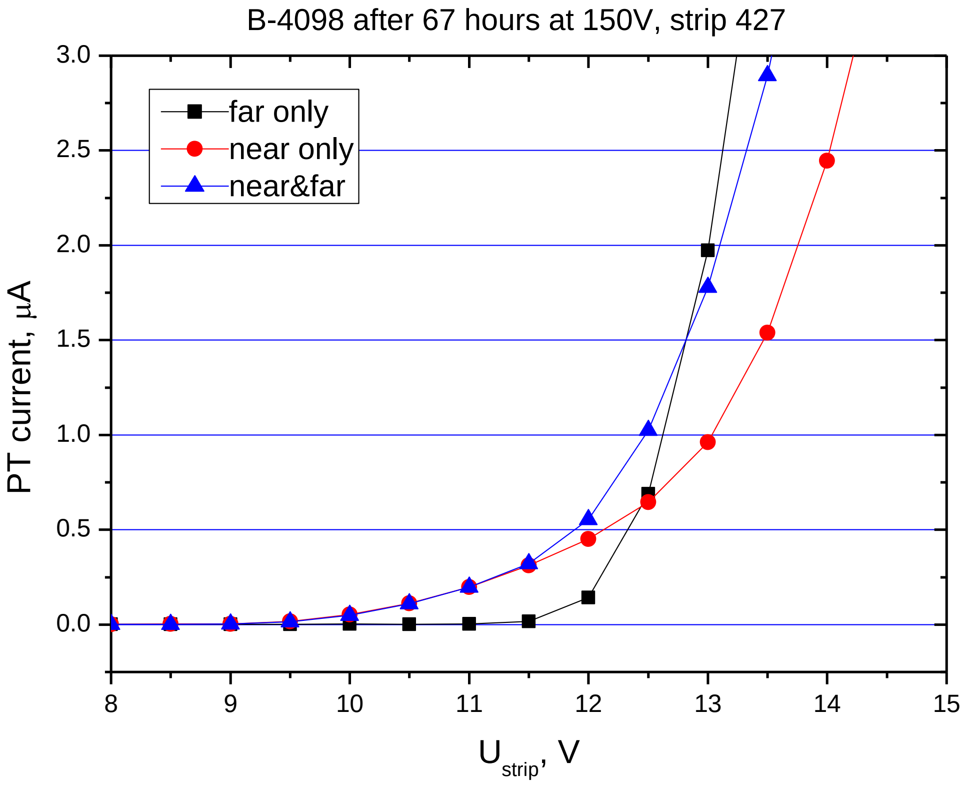

Fig.3. PT current around the PT onsets for different configurations

A special study was performed to understand whether the PT current leaks noticeably to the neighbouring strips. To this purpose the technique developed for the interstrip resistance measurement was used. The potential (V_{master}) was applied by a source-meter unit (SMU) between the implant and the grounded bias rail (BR) at a strip called "master". The SMU current (I_{master}) was measured and the ratio V_{master}/I_{master} was used to calculate the resistance, R_{sBR}, between the strip and BR. Simultaneously the potential (U_{slave}) induced on another strip (called "slave") was measured with a high impedance (>10 GΩ) voltmeter. The ratio of U_{slave}/V_{master} , which is a measure of the I_{master} leak to the "slave" strip, was found to be always much lower than 1. Typical results are presented below.

These tests were made again with barrel sensor B-4098 biased by 150V. The V_{master} potential was applied to strip 400 at the near side. Three strips: an immediate neighbour, 399, and two remote strips 371, 427 all contacted at the far end were used as the “slave” strips. The sequence of measurements was as follows. In the first series the V_{master} was changed in the interval from -4 to +4V i.e. far below the PT threshold of ~ 10 V. Four scans were made with the following strips used as a “slave”: 399, 427, 371 and 399 again. The relation between I_{master} and V_{master} was perfectly linear with the slope corresponding to 1.486 MΩ, which is the bias resistor value. Fig.4 shows U_{slave} as a function of I_{master}. The lines are linear fits to the data. The ± 4V change in V_{master} induced the change in U_{slave} of about ± 30μV i.e. ~ 10^5 times less. The signals induced at the immediate neighbour and the remote strips are very close which shows that their origin is not related to the leakage via interstrip resistance. Further interpretation of these results will be discussed later.

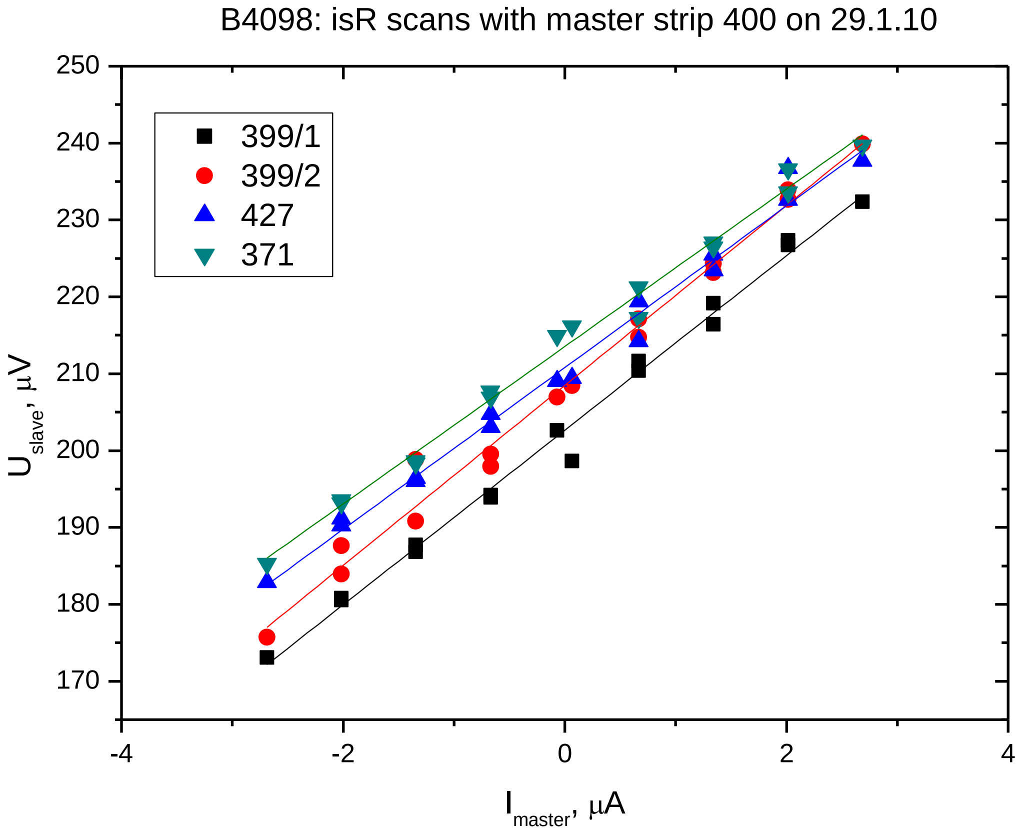

Fig.4. U_{slave} vs I_{master} for V_{master} in the range -4 ÷ 4 V.

In the second series four V_{master} scans were made in the interval from 1 to 23 V using the same “slave” strip sequence as before. Fig.5 shows the I_{master} vs. V_{master} with the scan start time indicated. The straight line corresponds to V_{master}/1.486 MΩ. Above ~10V the I_{master} starts to deviate from the line that indicates the PT development.

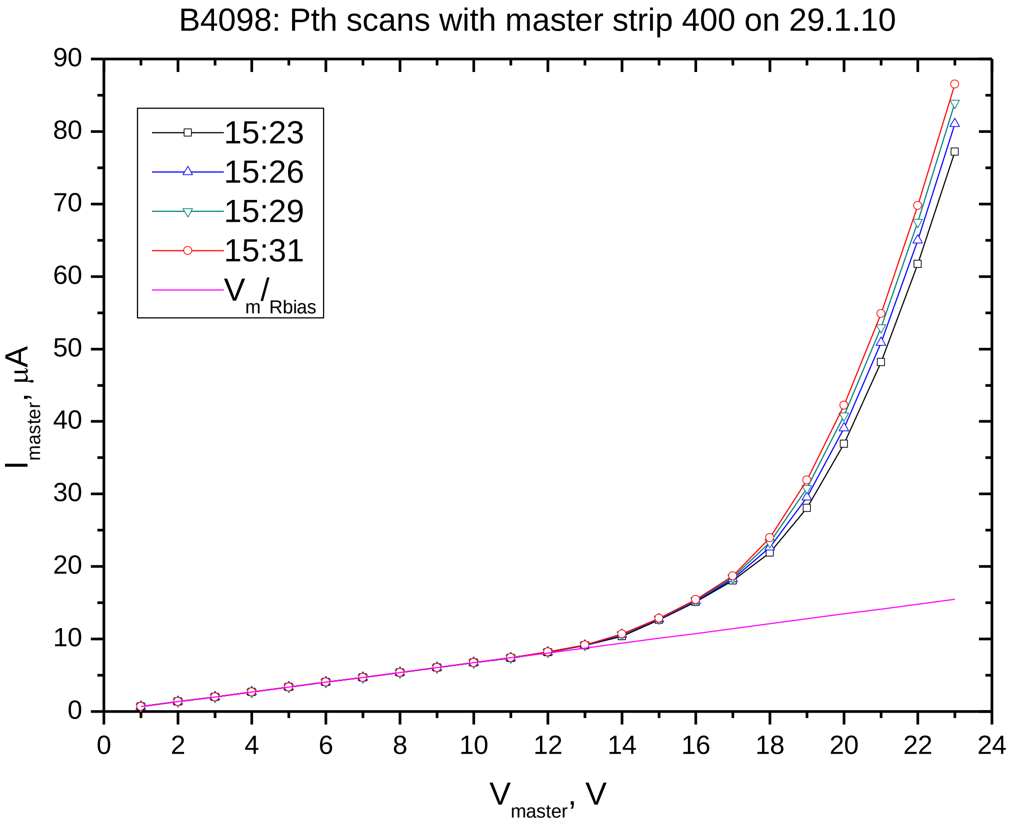

Fig.5. I_{master} vs. V_{master} in 4 consecutive PT scans

Fig.6 shows U_{slave} vs I_{master} in these scans with corresponding linear fits. Similarly to the results in Fig.4 the signals induced at the immediate neighbour and the remote strips are about the same. The dU_{slave}/dI_{master} slopes in Figs. 4 and 6 are also quite similar. This shows that the PT current spreads to neighbour strips not more than a normal current through the bias resistor.

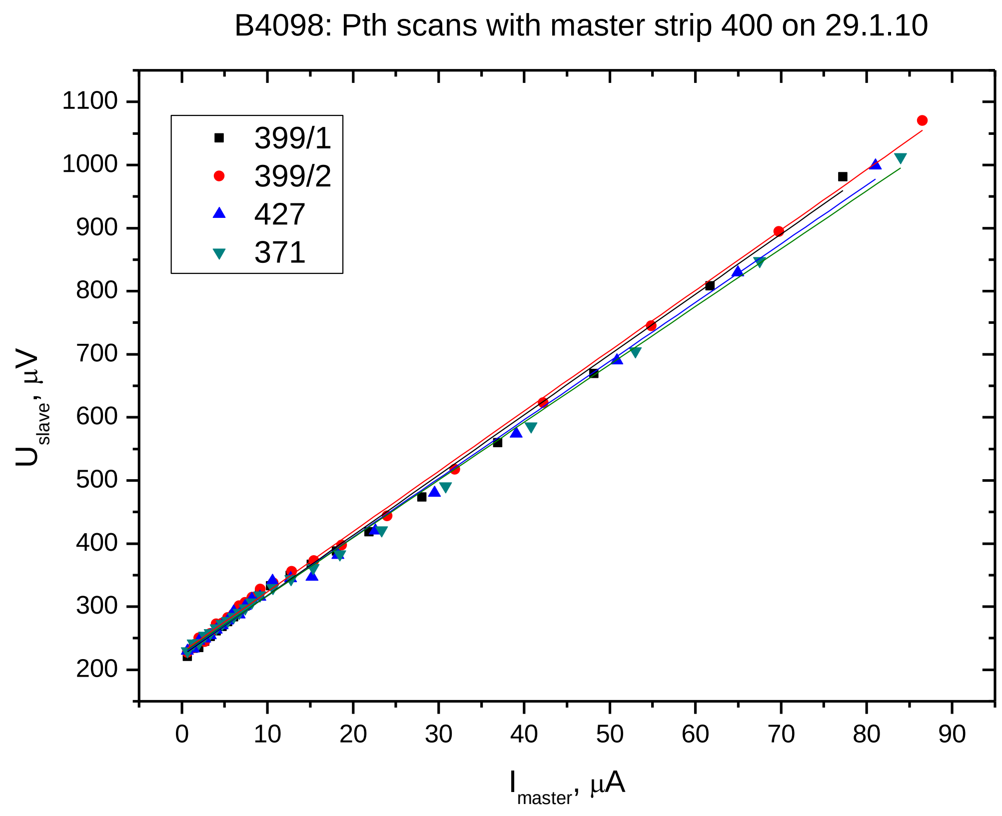

Fig.6. U_{slave} vs I_{master} for V_{master} in the range 1 ÷ 23 V.

Table 1 contains the results for dU_{slave}/dI_{master} obtained from the linear fits in different situations. First column corresponds to the data shown in Fig.4, second to the data from Fig.6 but only for the V_{master} in the range 1÷9 V i.e. below the PT onset. The third column corresponds to the lines shown in Fig.6. As was mentioned earlier, the slopes practically don't differ for next neighbour and remote strips. This shows that they are not related to the current leaking through a resistance between the strips. Most likely they are due to the resistance, R_g, between the point where bias resistors are connected to the BR and the ground, which includes the resistance of the BR itself and between the BR connection (which was at the far side near strip zero) and the ground. The current flowing from the master strip produces around the point where it arrives to the BR a potential equal to $I_{master}*R_g$, which should be about the same for all slave strips in the vicinity of the master one. Within this model the slopes given in Table 1 simply represent the R_g. Their values are low enough to be plausible.

Table 1. dU_{slave}/dI_{master} in Ω.

Strip/V_{master} range	**-4 ÷ 4 V**	**1 ÷ 9 V**	**1 ÷ 23 V**
399-1st meas.	11.4 ± 0.3	11.4 ± 0.3	9.6 ± 0.1
399-2nd meas.	11.7 ± 0.4	11.4 ± 0.9	9.6 ± 0.1
427	10.5 ± 0.3	11.0 ± 0.6	9.3 ± 0.1
371	10.2 ± 0.3	9.8 ± 0.4	9.2 ± 0.1

In all columns the slopes for the remote strips are slightly lower than that for the next neighbour. On the one hand it can reflect a small contribution from the direct leak through the interstrip resistance, but it can also result from a slightly different potential induced at relatively large distance of ~30 strips from the master strip. As one could expect the slopes in the second column don’t differ from those in the first one. Lower slopes in the third column can be due to the fact that part of the PT current flows to the BR from the far end of the master strip and therefore its contribution to the potential at the near side is suppressed. Measurements with other strips in the same sensor gave similar results.

In conclusion, the punch-through develops at both sides of the strip with close onset values. For the near side the PT onset can be even lower than that for the far side in spite of a significantly larger PTP gap at the near side. The data also indicate that the PT current flows directly to the bias rail without spreading to the neighbour strips. It would be very useful to understand where exactly the PT develops, especially at the near side.