Silicon Microstrip Detectors for the ATLAS SCT

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for the ATLAS SCT

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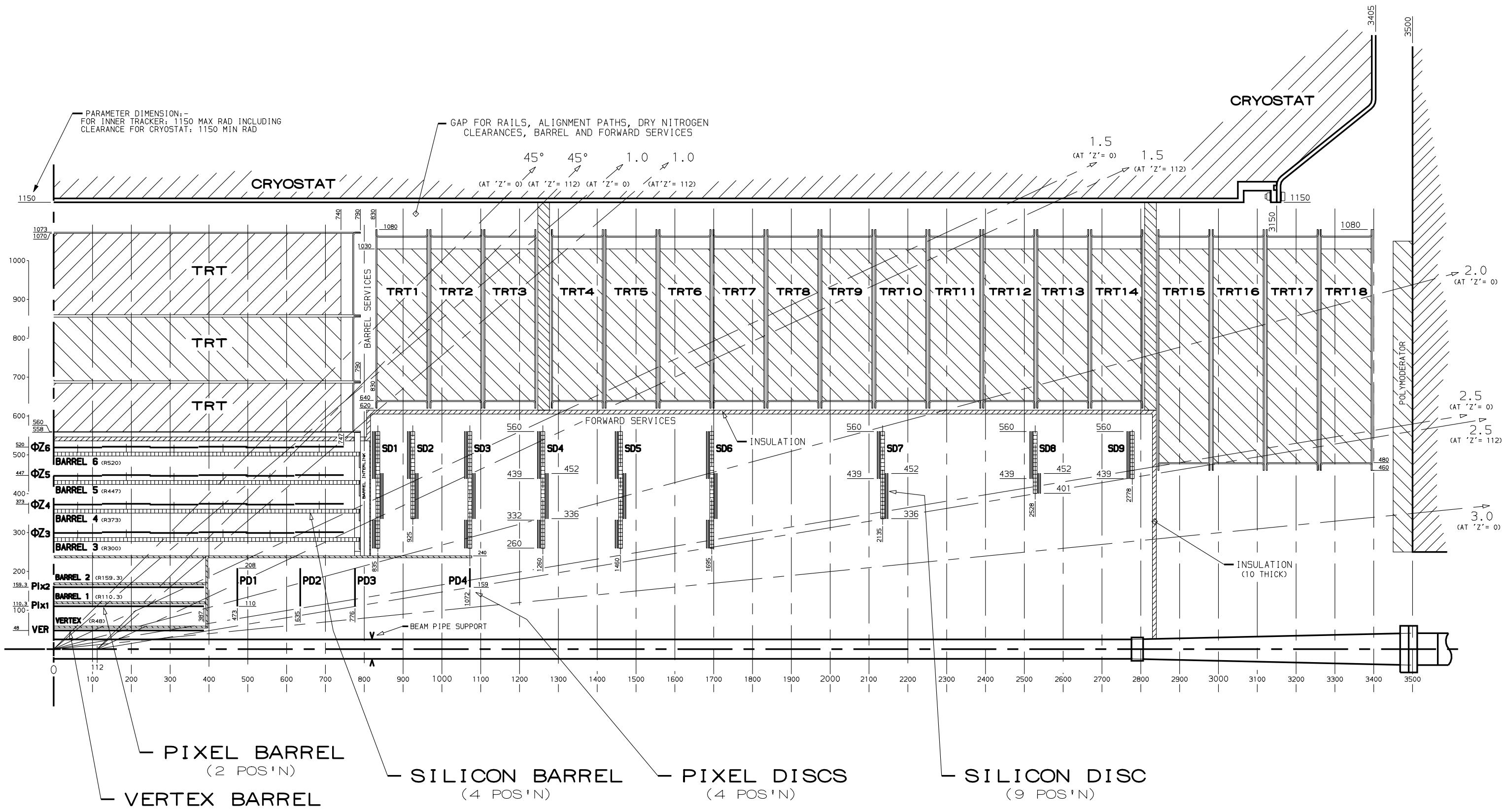
- The ATLAS SCT
- Sensor Design and Specifications
- Sensor Development - prototype to production
- Production Schedule & QA Strategy
- Quality Control during Production
- Summary

This talk is available as a PDF file from www.hep.phy.cam.ac.uk/silicon

The ATLAS SemiConductor Tracker

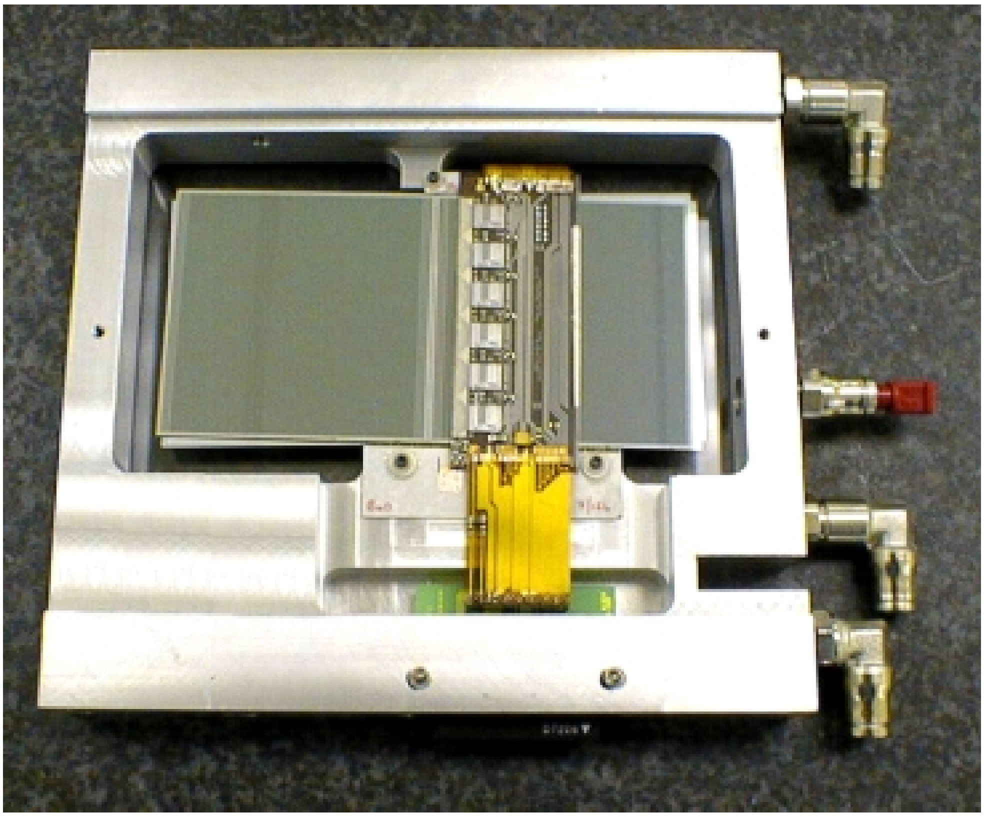
The SCT comprises 4 barrel layers and 9 end-cap wheels on each side, incorporating a total of ~60m^2 of silicon. The barrel region uses ~10600 sensors with rectangular geometry, and the end-cap wheels use ~8700 wedge shape sensors.



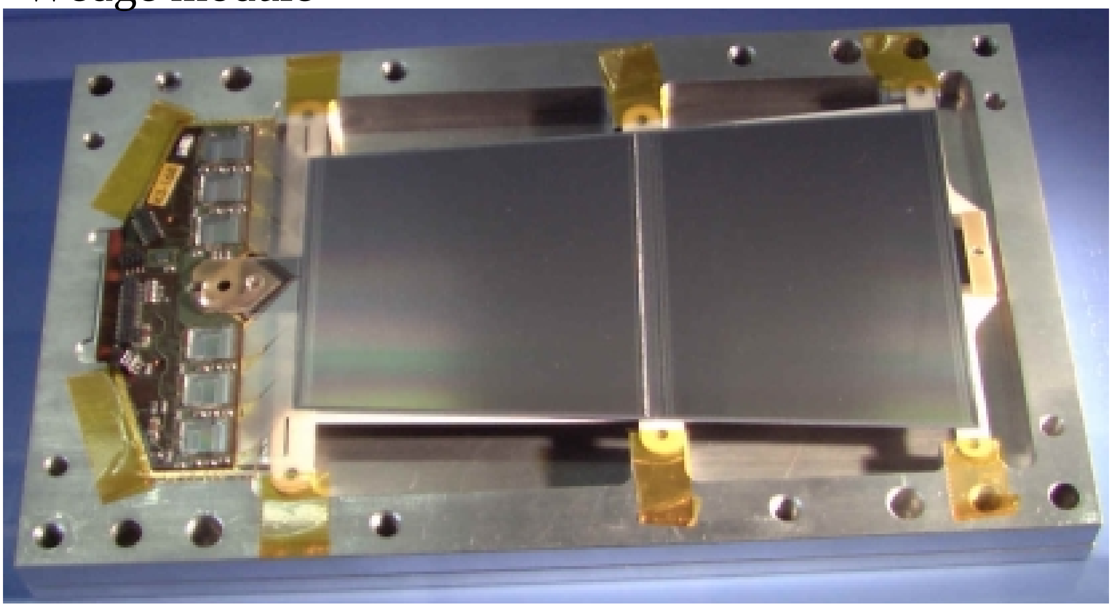
Cross-Section through right side of ATLAS Inner Detector

ISSUE Q
ATLAS INNER TRACKER GEOMETRY
DIMENSIONS FOR TDR 1997
1-TB-0035-060-00-Q
04MAR97

Barrel Module

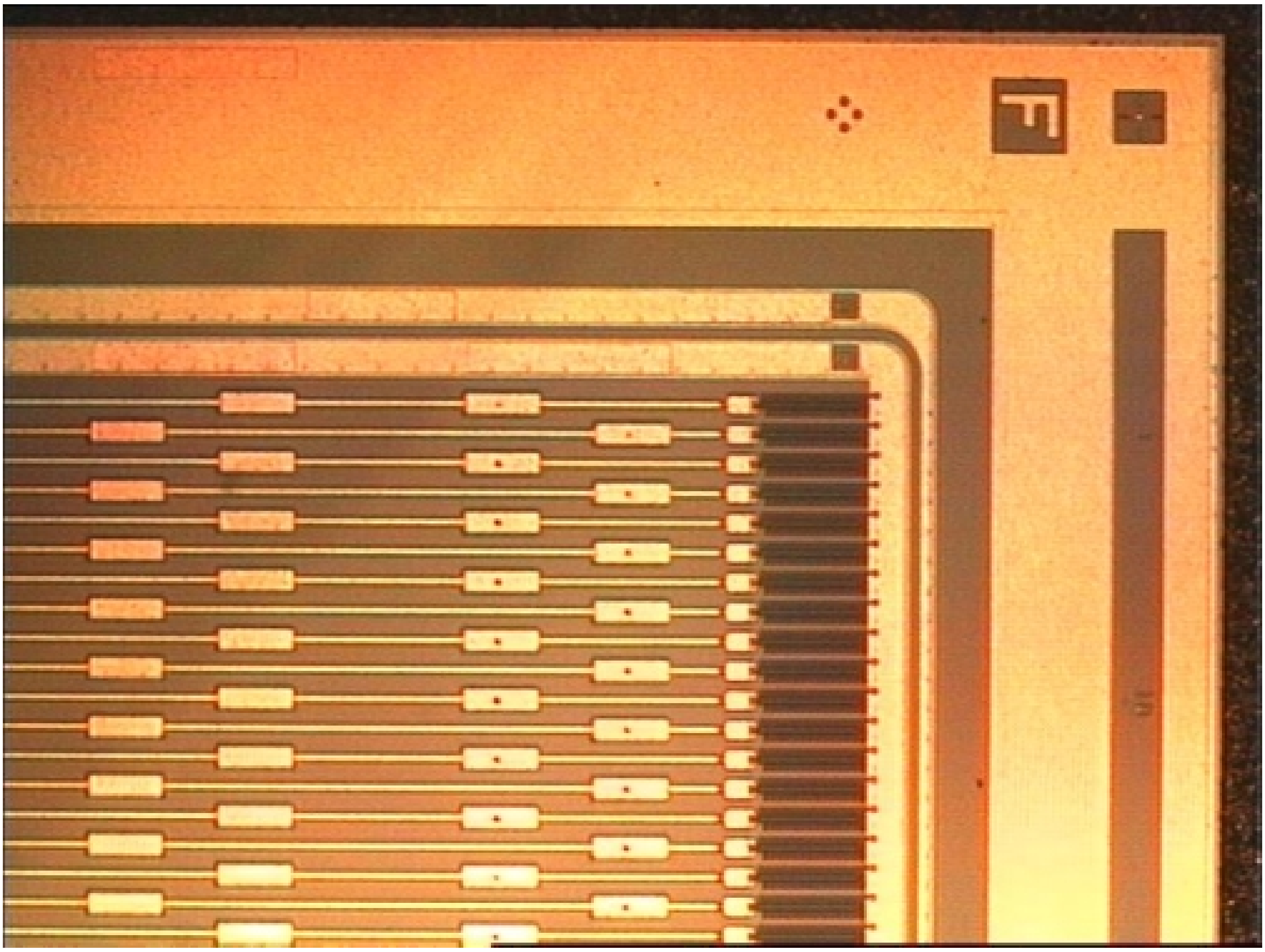


Wedge module



Barrel Sensor Design

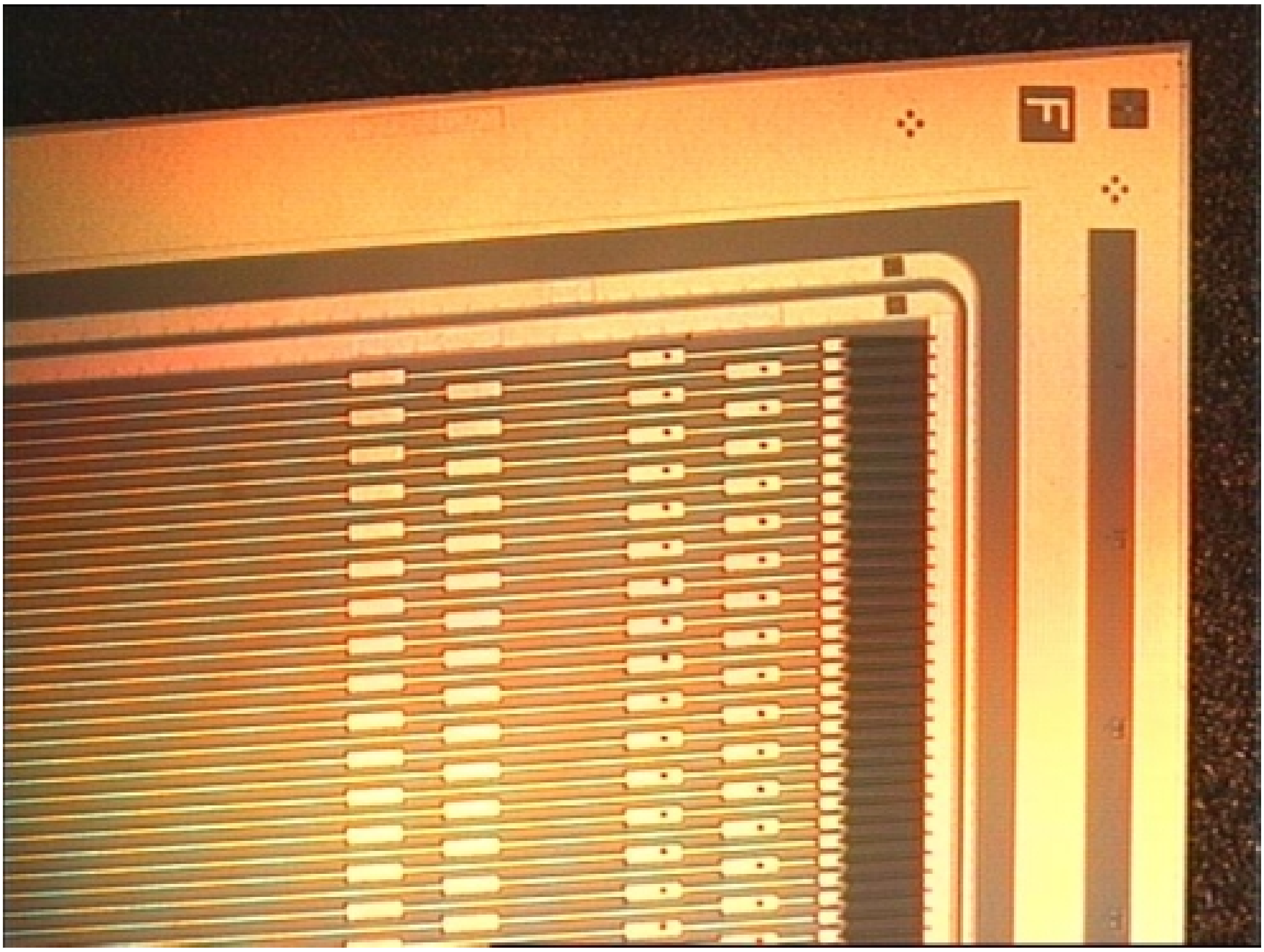
Hamamatsu barrel



- 64 x 63.6mm (active area 62 x 61.6mm) x 285µm
- 768 AC-coupled strips at 80µm pitch (+2 dummies)
- Bias resistors at one end
- Reach-through protection 5-10µm implant-to-bias rail
- Strip metal width / Implant width = 16-22 / 16-20 µm
- HV contact: metallised non-passivated n-implant on back, also front contacts to edge-implants for pre-irradiation QA
- Optimised edge termination (manufacturer-dependant)

Wedge Sensor Design

Hamamatsu W12



- Five geometries: W12, W21&W22, W31&W32

	Length(mm)	Outer Width(mm)	Inner Width(mm)	Pitch(μrad)
W12	61.06	55.488	45.735	207
W21	65.085	66.13	55.734	207
W22	54.435	74.847	66.152	207
W31	65.54	64.636	56.475	161.5
W32	57.515	71.814	64.653	161.5

Manufacturers

Following the process of qualification of their sensors, and competitive tendering, 3 companies were awarded contracts to supply the SCT microstrip sensors.

	Hamamatsu	**CiS**	**Sintef (*)**
Contribution:	79%	17%	4%
Sensor types:	All	Wedges only	Barrels only

It is not realistic to ask different manufacturers to fabricate sensors from a common design 'template' because sensors from different manufacturers are fabricated using their own commercially-confident design rules and processing techniques.

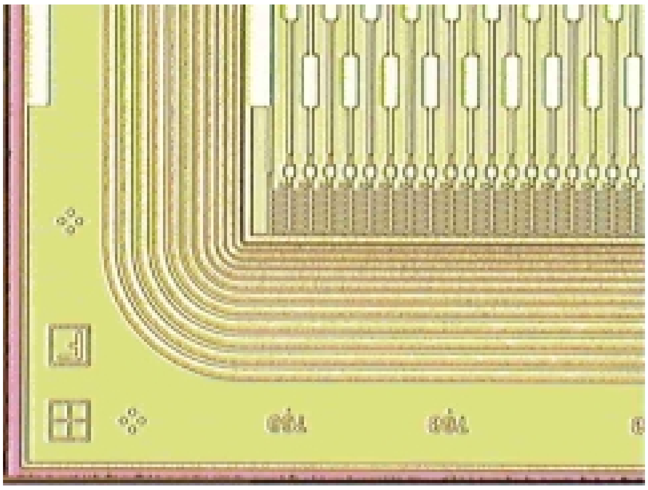
Therefore detailed design issues and choice of substrate are at the discretion of each manufacturer.

However, for people building ATLAS SCT modules, the sensors look identical (ie same overall geometries, and locations of bond pads etc)

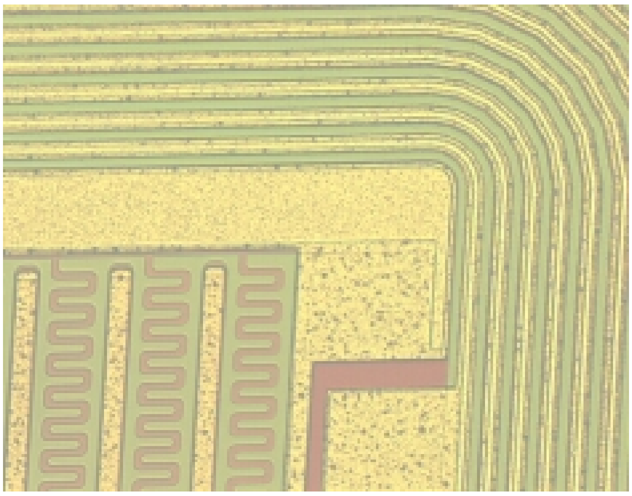
(*) At the time of this conference, the contribution from Sintef is subject to on-going qualification tests

Differences between Manufacturers

	Hamamatsu	**CiS**	**Sintef**
Substate Orientation:	<111>	<111>	<100>
Oxygenation:	None	W12 only(*)	None
Bias Resistors:	Polysilicon	Implant	Polysilicon
Edge Design:	Single Guard	14-multiguard	11-multiguard
Strip Dielectric:	Composite stucture, manufacturer-dependent		



Corner Detail - Sintef Barrel



Implant resistors - CiS Wedge

(*) at the time of this presentation, the contribution from oxygenated CiS W12 sensors are still subject to qualification tests

Acceptance Criteria - Pre-Irradiation Characteristics

- Total leakage current at 20°C:
  <6μA@150V and <20μA@350V
- Leakage current stability: to increase by no more than 2μA @150V in dry air over 24 hours
- Depletion Voltage < 150V
- R_{bias} = 1.25 +/- 0.75 MΩ
- $C_{coupling}$ >= 20 pF/cm @ 1kHz
- $C_{interstrip}$ < 1.1pF/cm @ 100kHz @ 150V bias
- $R_{interstrip}$ > 2 x R_{bias} at operating voltage
- Strip metal resistance < 15Ω/cm
- Strip quality: a mean of >99% good readout strips per detector in each delivery batch, with no detector having less than 98% good strips.

A strip is counted as defective if any of the following conditions apply:

- *An electrical short through the dielectric with 100V applied between the metal and substrate*
- *Metal break or metal short between neighbours*
- *Implant break or implant short between neighbours*
- *Implant strip connection via resistor to bias rail broken*

Acceptance Criteria - Post-Irradiation Characteristics

During Irradiation

• Detector leakage current should increase in a stable and monotonic fashion

After $3x10^{14}$p.cm^{-2} and 7 days anneal at 25^{o}C:

• Total leakage current <250µA up to 450V @ -18^{o}C

• Leakage Current stability: to vary by no more than 3% in 24 hours at 350V at -10^{o}C

• Strip defects: Number of strip defects (dielectric & metal) within pre-irradiation acceptance level

• R_{bias} to remain within pre-irradiation limits

• $R_{interstrip}$ > 2 x R_{bias}

• Charge collection: Maximum operating voltage for >90% of maximum achievable charge : 350V (checked with SCT128A analogue readout at 40MHz)

• Microdischarge: must be <5% increase in measured noise on any channel due to microdischarge when raising detector bias from 300V to 400V (checked with readout electronics running at 40MHz)

Sensor Development

from Prototype to Production

- 1995-1999
  Prototyping, including n-on-n

- Early 1999
  Formal qualification of manufacturer

- Late 1999
  Competitive tendering, contracts awarded

- Jan-Apr 2000
  PreSeries Production

- Jan 2001 - late 2002
  Full scale production (in progress)

Sensor Qualification

• Interested manufacturers were invited to supply several of their optimised prototype sensors that should meet ATLAS specifications. The prototypes were evaluated extensively by ATLAS both before and after irradiation to ~$3x10^{14}$p.cm^{-2}.

• Only those manufacturers that had supplied *several* prototypes (nominally 10) with identical processing that gave consistent characteristics and were within all ATLAS specifications before and after irradiation were considered to be qualified.

• Four companies qualified their sensors, and after competitive tendering three of these companies (Hamamatsu, CiS, Sintef) were awarded contracts to supply the SCT sensors.

• Before full scale production, companies were required to deliver a preseries production (~5% of their total order)

PreSeries Production (Jan-April 2000)

Manufacturers were initially required to supply a preseries production, which comprised ~5% of their total delivery. The preseries was used to demonstrate:

- that the quality of the produced sensors will be maintained, with characteristics consistent with the qualified sensors.
- the ability to comply with delivery schedules
- the ability of both the manufacturer and ATLAS to effectively implement the QA procedures
- compatibility of QA data between the manufacturer and different ATLAS institutes
- the effectiveness of packaging, labelling, transportation and other procedural and QA issues

A Production Readiness Review in August 2000 approved the release of funds for the full series production.

4. Series Production (Jan 2001 to late 2002) .... Is currently underway!

Manufacturers are contractually obliged to deliver detectors in regular monthly shipments, distributed to the 7 module-building clusters in ATLAS:

• CE: Freiburg, MPI, Nikhef, Prague, Potvino

• UK-V: Glasgow, Lancaster, Liverpool, Manchester, RAL, Sheffield, Valencia

• CS: Australia, CERN, Cracow, Geneva, Llubljana, MSU, Prague, MPI

• Nordic: Bergen, Oslo, Uppsala

• Japan: Hiroshima, Tsukuba/KEK, Kyoto edu, Okayama

• USA: LBL, UCSC

• UK-B: Birmingham, Cambridge, QMW, RAL

red indicates QA institute

Each of the module-building clusters has one or two institutes that receives the detectors and performs all the QA. The receiving ATLAS institute has three months to perform all QA tests before payment is due.

Eg: Schedule at Cambridge:

• *total delivery: 2300 Hamamatsu barrels*

• *monthly batch size: 120*

• *Jan 2001 to August 2002.*

Acceptance Criteria - Mechanical Properties

Not all mechanical properties are easily quantifiable, and some may be quantified somewhat arbitrarily. However, it is important to state all possible problems and to set reasonable limits where possible to ensure that manufacturers are contractually obliged to take back detectors that are mechanically defective

- Quality of cut edges: Edge chipping to be avoided, no chips or cracks to extend inwards by > 50µm
- Damage and Defects: Device free from scratches and other defects that ATLAS judges could compromise the detector performance during the lifetime of the experiment. The criteria were mainly established in collaboration with the manufacturer during the pre-series production, and may continue to evolve.
- Thickness: 285 +/- 15µm
- Uniformity of thickness: 10µm
- Flatness: Sensors must be flat to 200µm when unstressed
- Mask alignment tolerance: <3µm misalignment
- Bond Pads: Metal quality, adhesion and bond pad strength to be such as to allow successful uniform bonding to all readout strips using standard bonding techniques.
- Alignment fiducials: Must be visible

QA Strategy

The Manufacturer

Following the process of qualification of a detector from a particular manufacturer, it is the responsibility of the manufacturer to ensure no changes in processing occur during production that may modify:

• any parameters relevant to ATLAS specifications

• any pre- and post-irradiation electrical behaviour

from that observed during the qualification program.

ATLAS

As consistency of processing is ensured, the role of ATLAS is mainly that of a visual examination and IV measurement on every detector as a basic check on quality. However, on a subset of detectors (~10%), an extensive evaluation of detector characteristics is performed as a check on processing consistency and as a verification of the manufacturers tests.

Furthermore, samples of detectors (<1%) will be regularly irradiated throughout production to ensure that the post-irradiation behaviour of the qualified detectors is being maintained.

Quality Control by the Manufacturer

The manufacturer is expected to perform sufficient checks to ensure consistency of processing and to maintain all electrical parameters within ATLAS specifications.

In addition, the manufacturer is expected to perform the following test measurements on *every* detector, and to supply the results to ATLAS:

• IV to 350V

• Depletion Voltage

• Determine strip dielectric shorts with 100V across across the dielectric (and must ground the strip metals afterwards!)

• Determine strip metal breaks

• Determine strip metal shorts to neighbours

Quality Control Procedures by ATLAS

- Compulsory tests on every sensor

  (Detector placed on probestation chuck)

  - Visual examination (~8 mins)
  - IV scan to 500V

- Tests on a subsample (~10%)

  (Detector mounted into frame)

  - Depletion
  - Full Strip Test
  - Metal Resistance
  - (interstrip capacitance)

- Tests on irradiated sensors (<1%)

  (after $3x10^{14}$p.cm^{-2} and 7 days anneal at 25^{o}C)

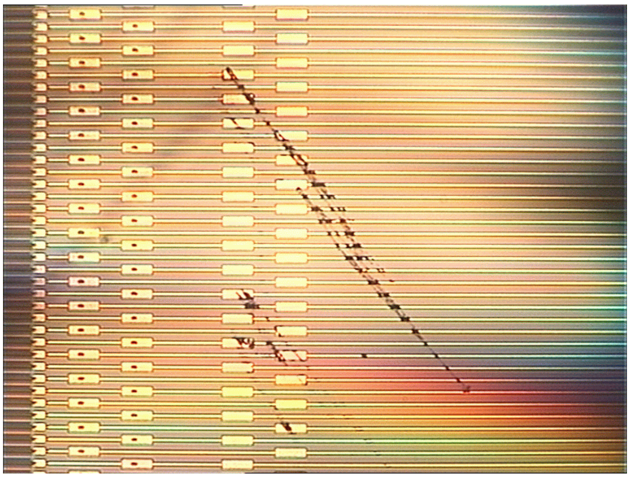
  - IV scan to 500V
  - Plateau in Signal vs bias (analogue r/o)
  - Strip noise distribution (binary/analogue r/o)

Visual Inspections

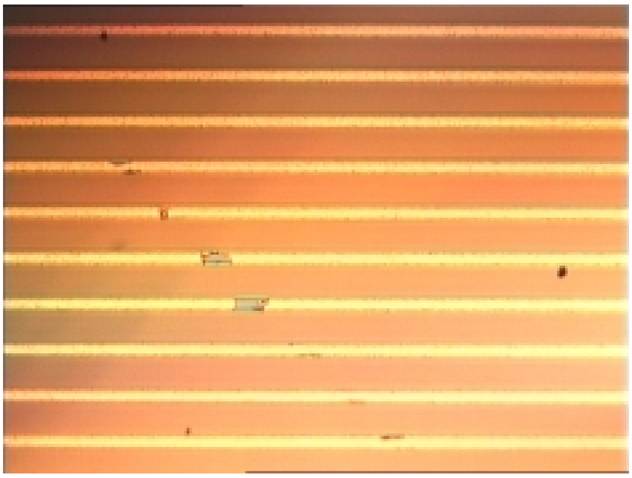
Full sensor area scanned under a microscope (automated probestation). Sensor must be free from “gross defects and scratches” and edge chips must not exceed 50μm.

What is a “gross defect”?

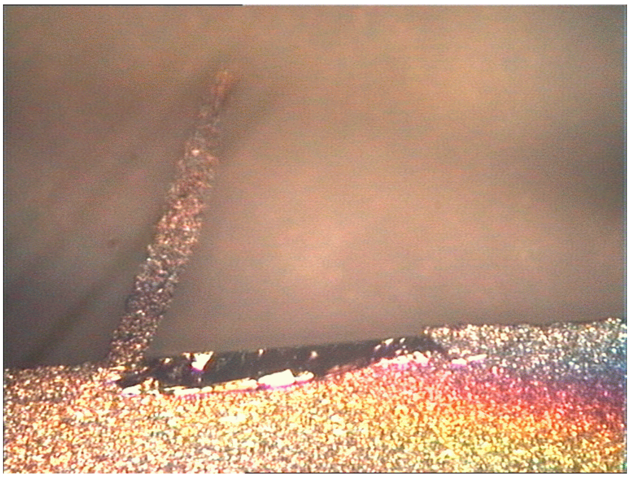
› *Requires judgement by operator, and agreement with manufacturer:*



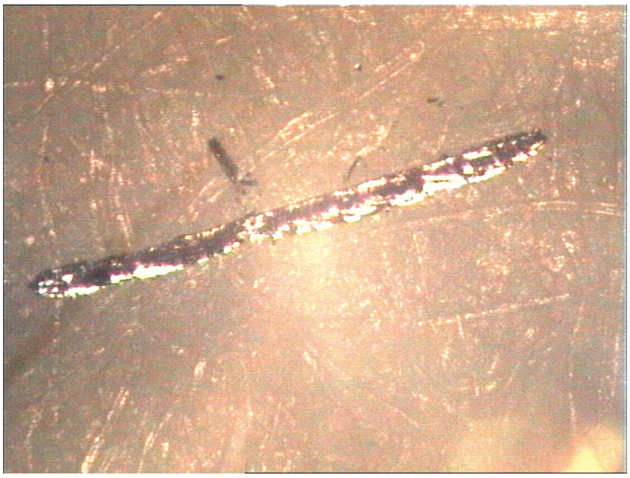
REJECT



ACCEPT



Rear Edge Chip REJECT

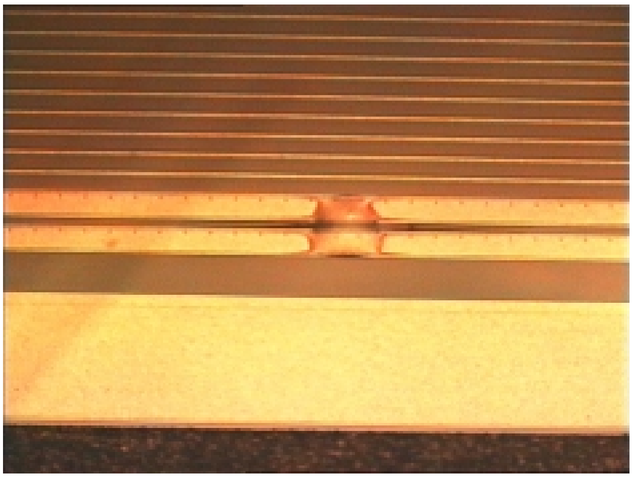
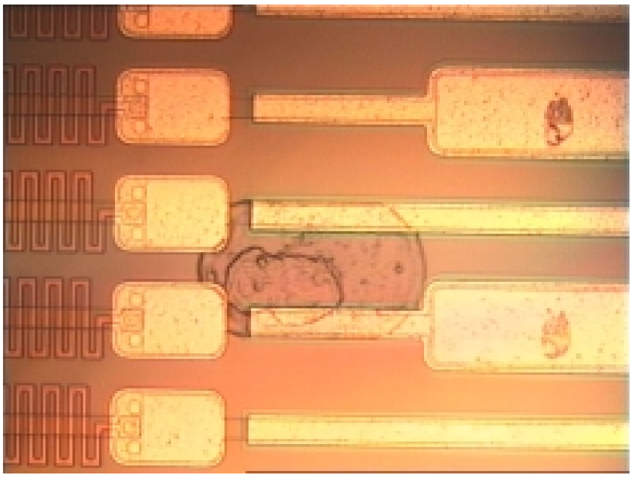
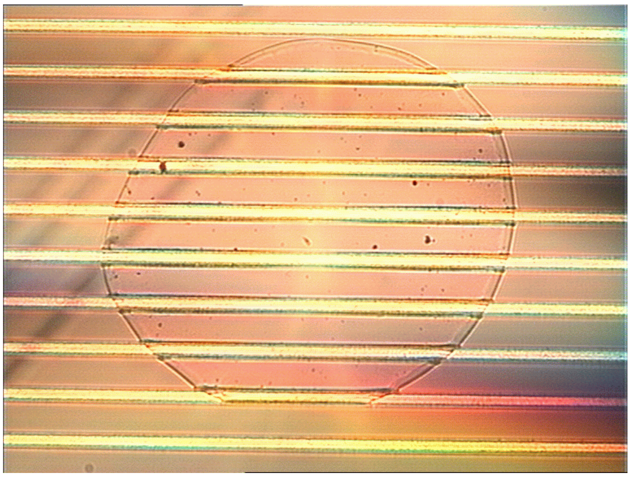
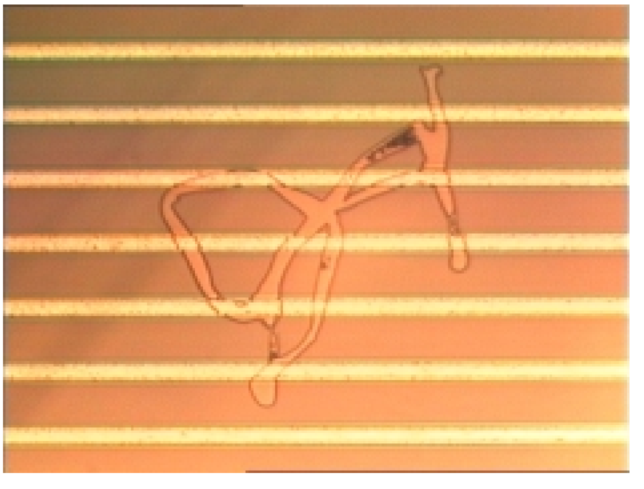


Debris in packaging from edge chipping poses danger

Visual Inspections

What about general visual curiosities?

Almost certainly harmless, but if frequently occurs (eg observed several times in a batch of ~100 sensors), choose as candidate for irradiation:

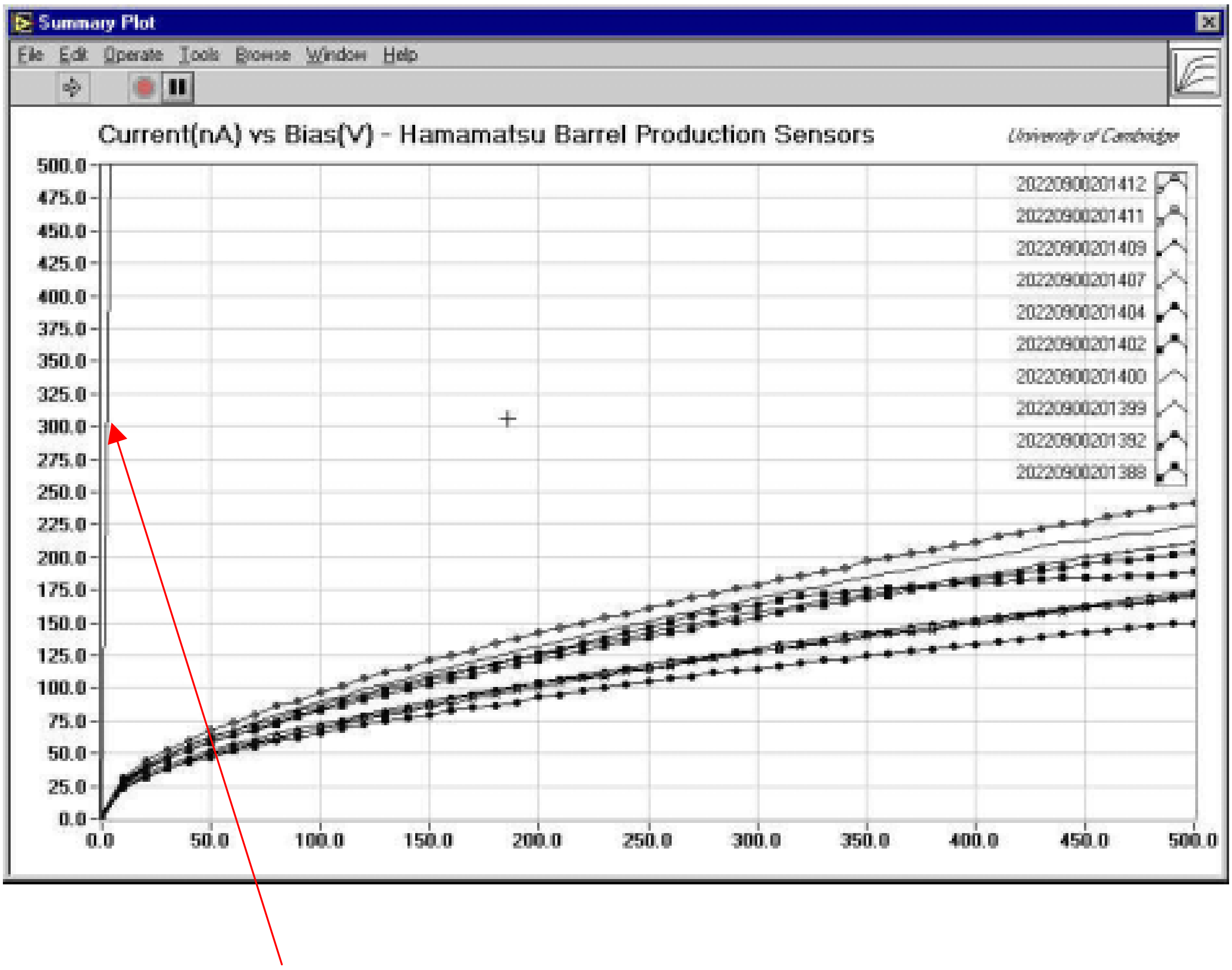
Leakage Current Tests

Measure from 0 to 500V in 10V steps, reject if any of the following apply:

• I> 6µA@150V

• I>20µA@350V

• ΔI(ATLAS-manufacturer) > 2µA@150V or 4µA@350V

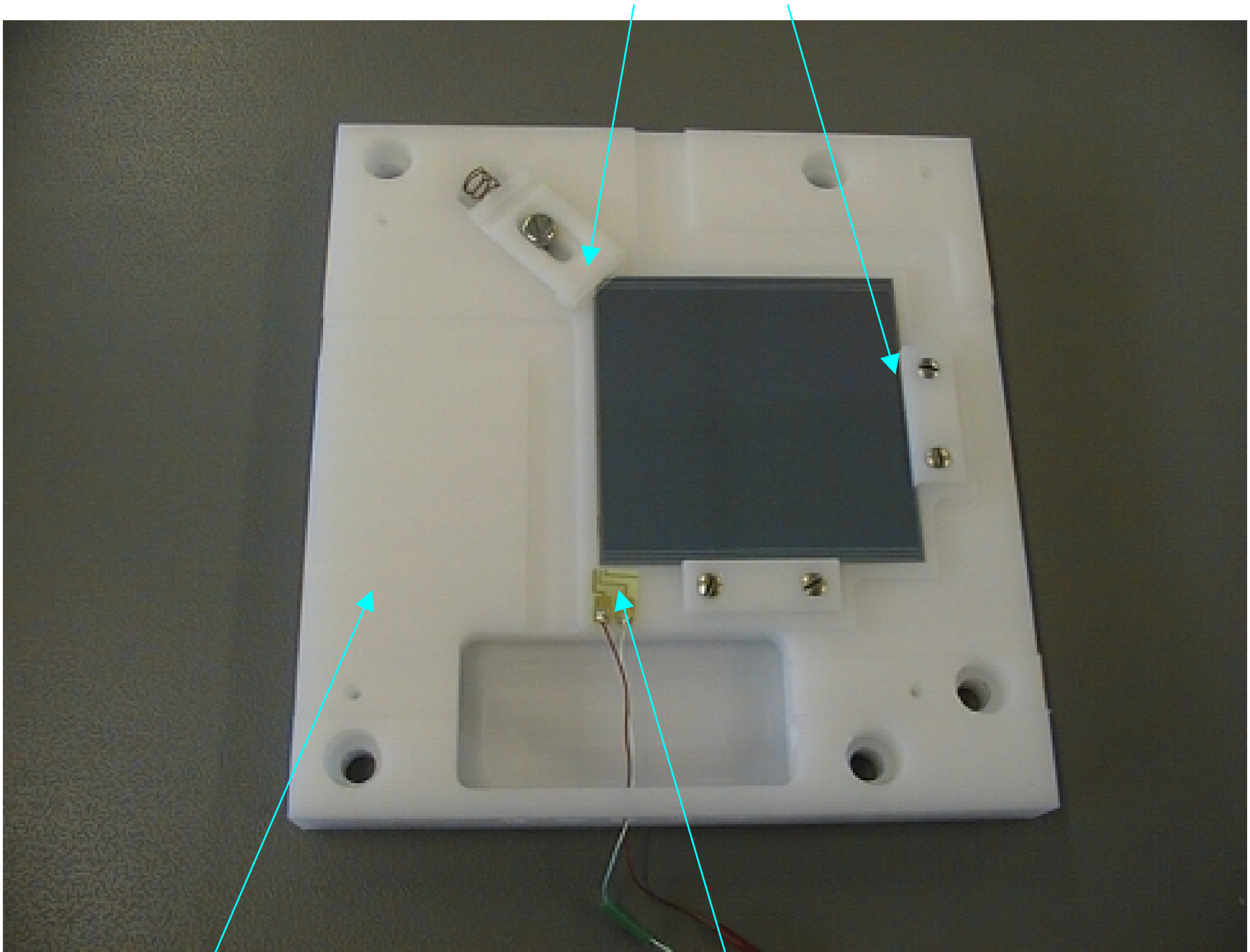


Fails ΔI test only

NB: Hamamatsu agreed ΔI rejection criteria to be tightened to 1µA

For more extensive tests (on ~10% of total sample), detectors are held and bonded into a frame to minimise risk of damage by excessive handling

Sensor held in by very light spring pressure between 3 delrin clamps



Delrin support block

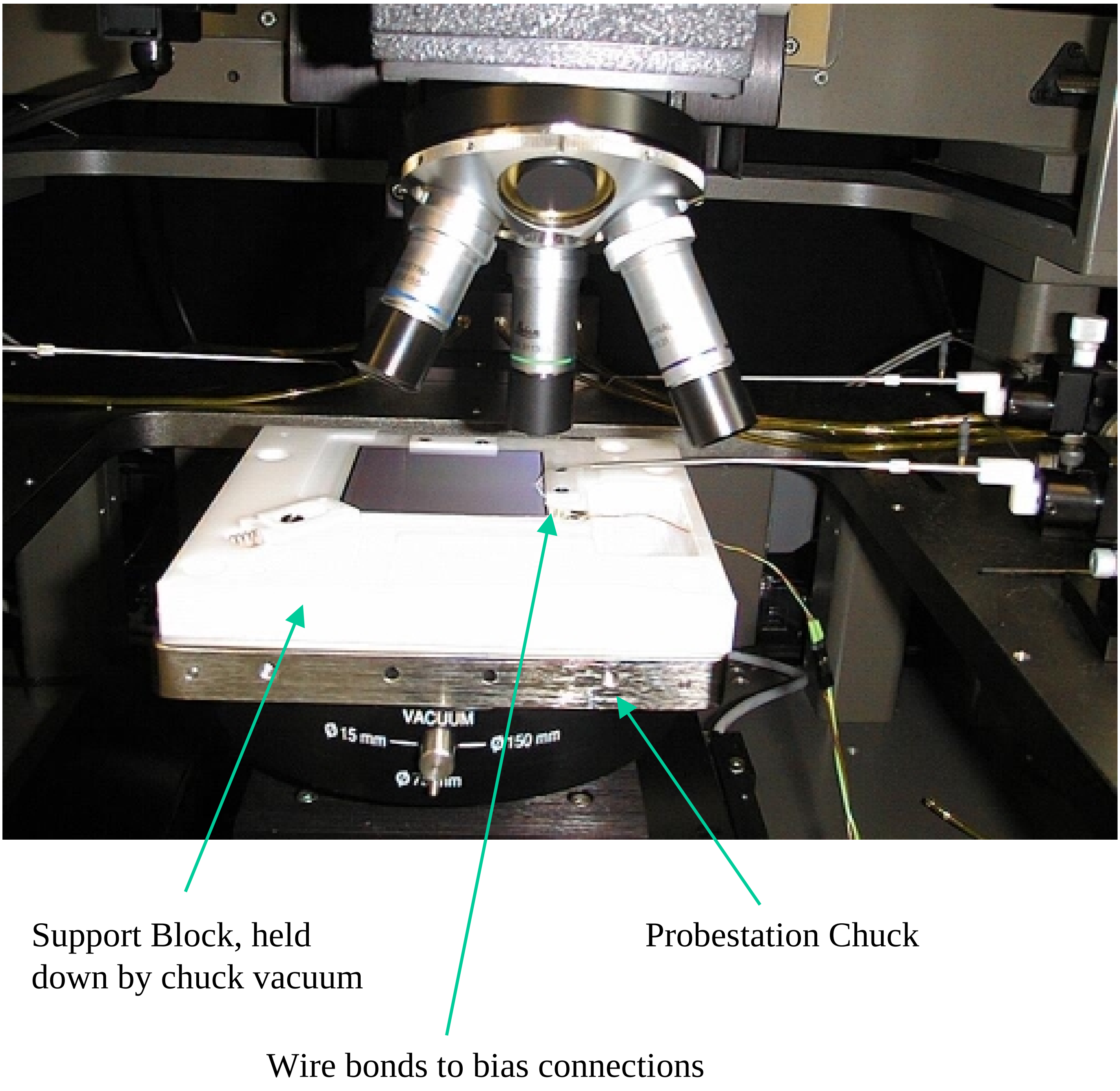
Bias connections, bonded to bias rail (gnd) and edge implant (HV)

Leakage Current Stability Test at Cambridge

5 detectors on support blocks, with bias connections wire bonded out to soldered leads.

Environment Chamber

Full Strip Test Setup at Cambridge

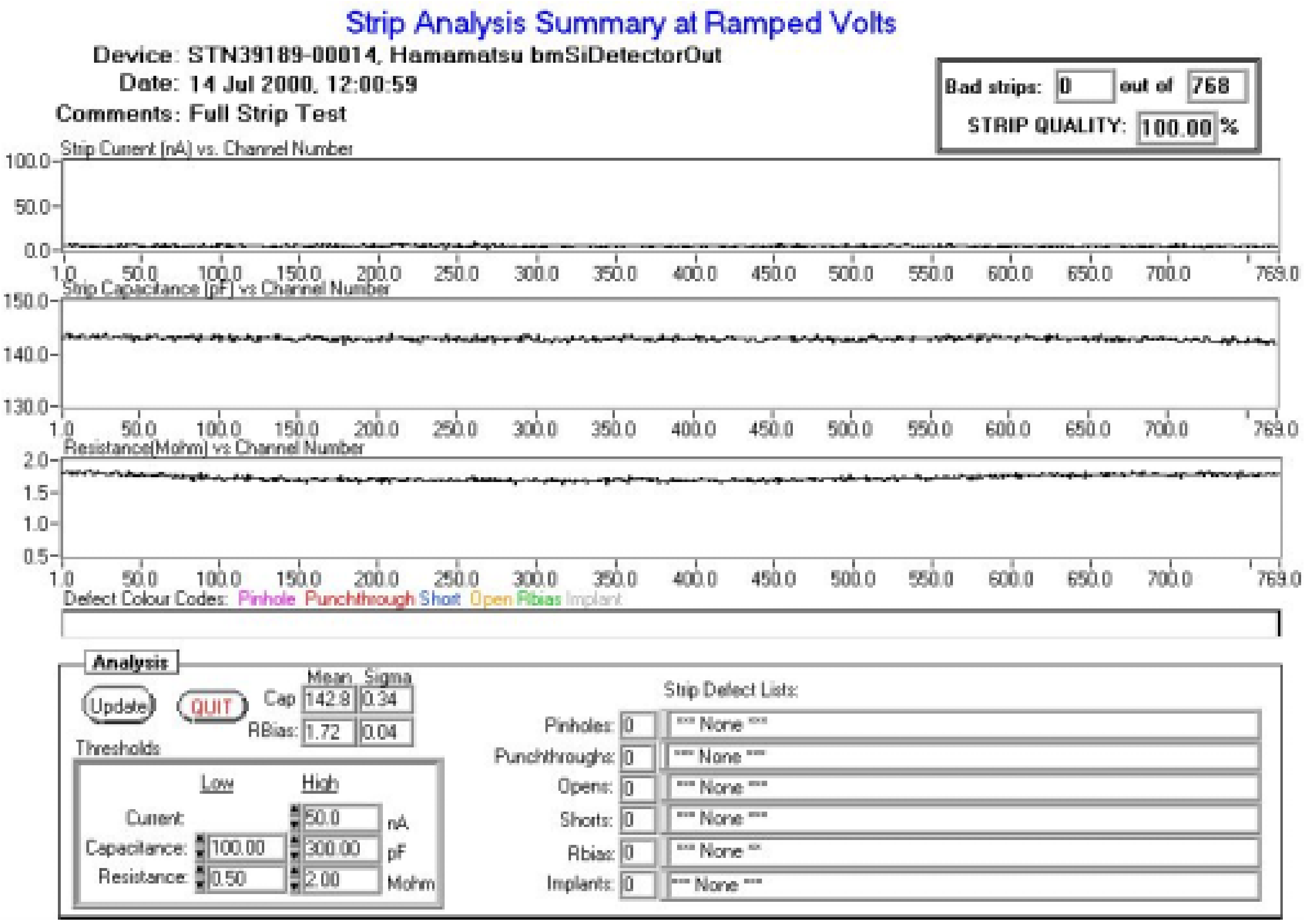


Full Strip Test

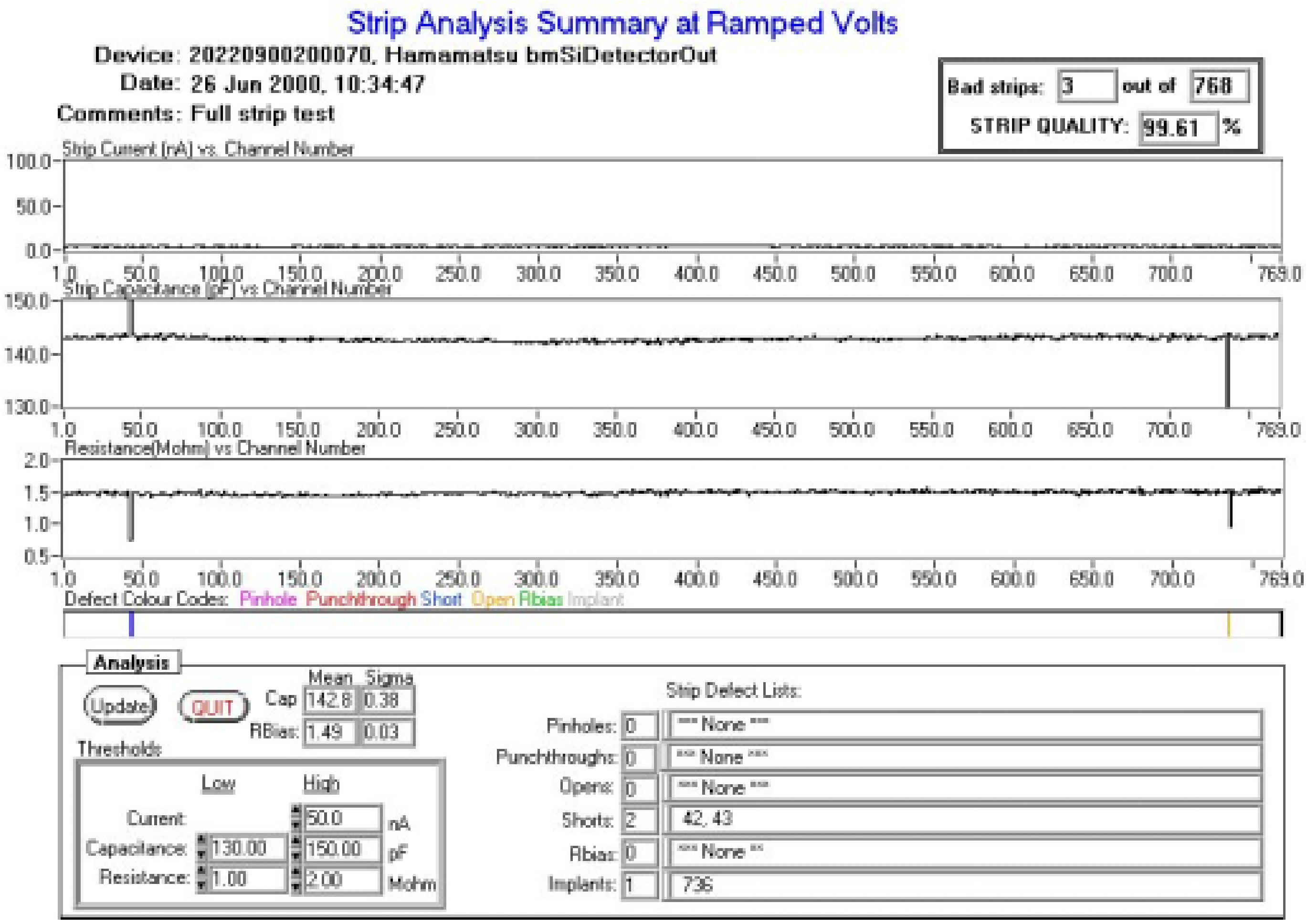
With the sensor partially biassed (to ~50% of full depletion voltage), step through every strip to probe the strip metal. For every strip, apply 100V across strip dielectric to determine robustness of dielectric, then return strip metal to ground and model CR in series on the measured impendance @100 Hz between strip metal and bias rail

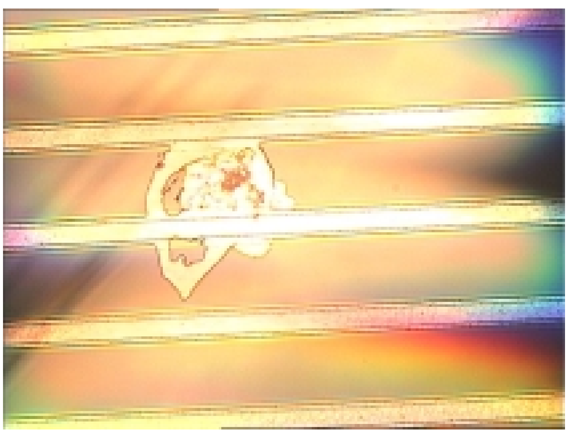
- $C = C_{coupling}$ $R = R_{bias}$

Sensitive to any strip defect, and any general processing defect that may effect operation of sensor, and yields the bias resistance and coupling capacitance for every strip.

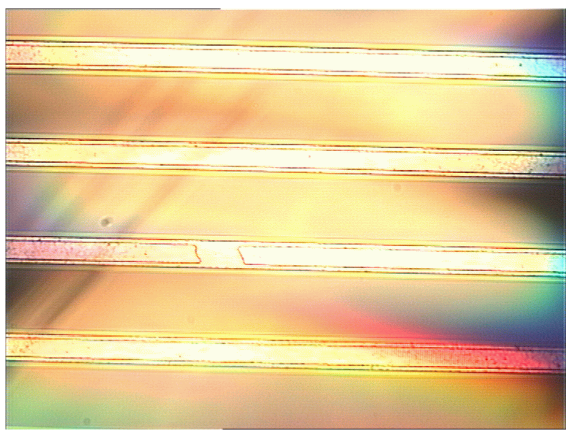


Detection of implant breaks, strip metal defects



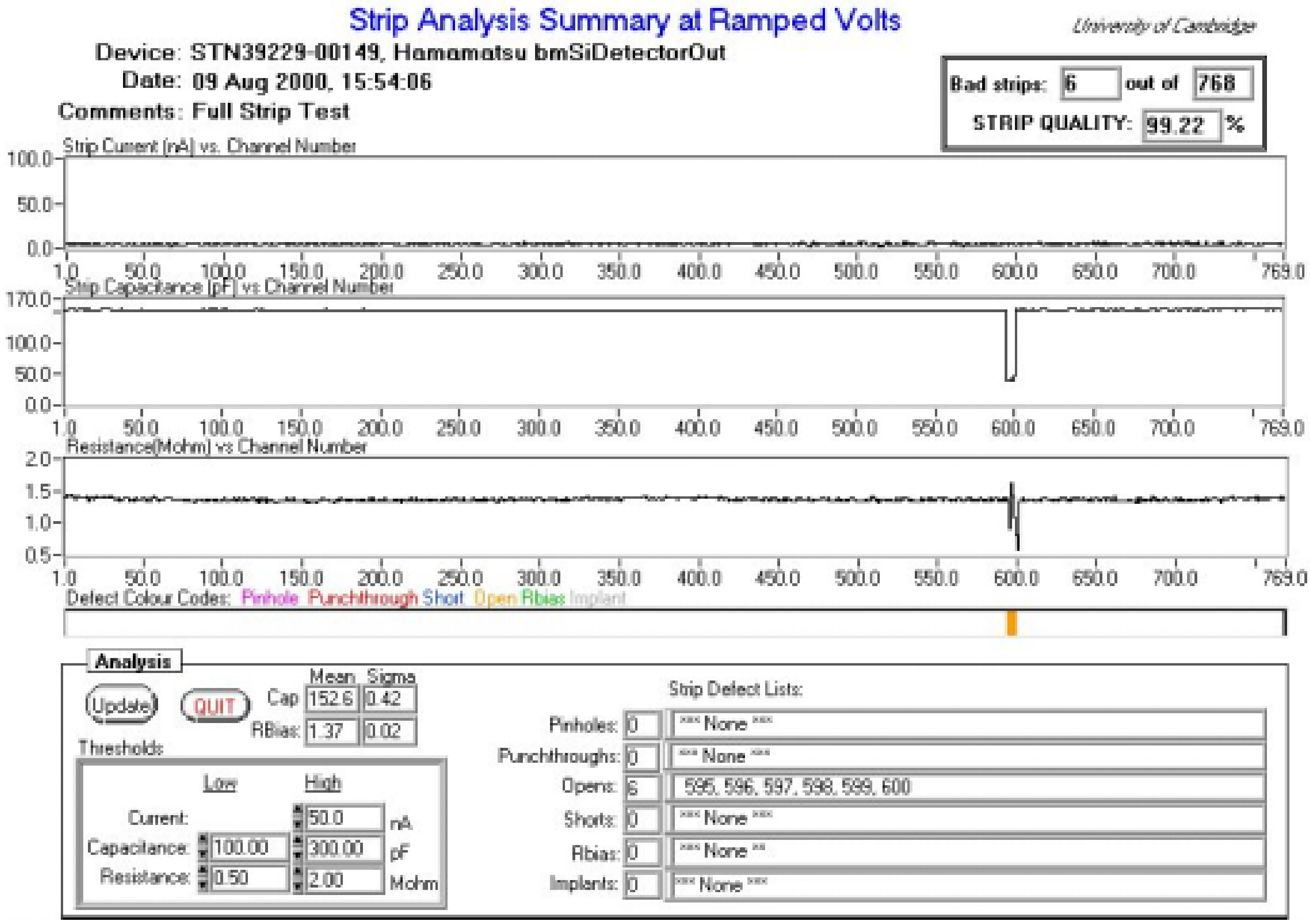


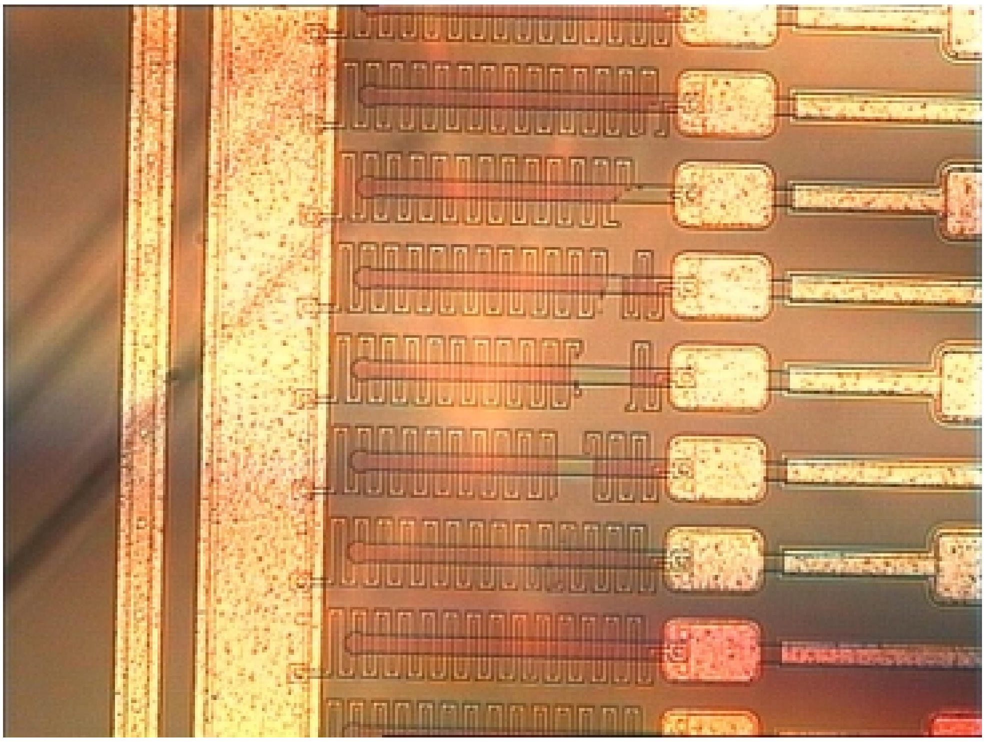
Metal short



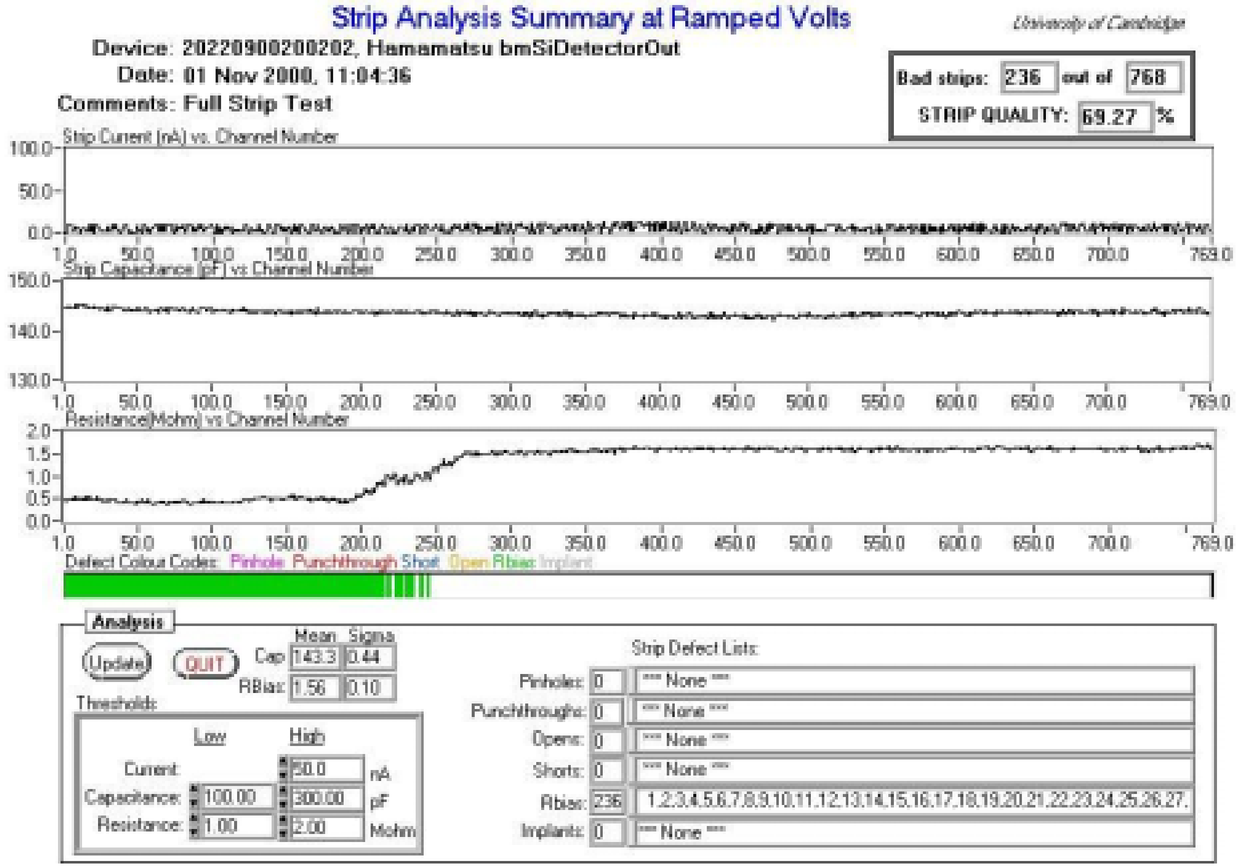
Implant break

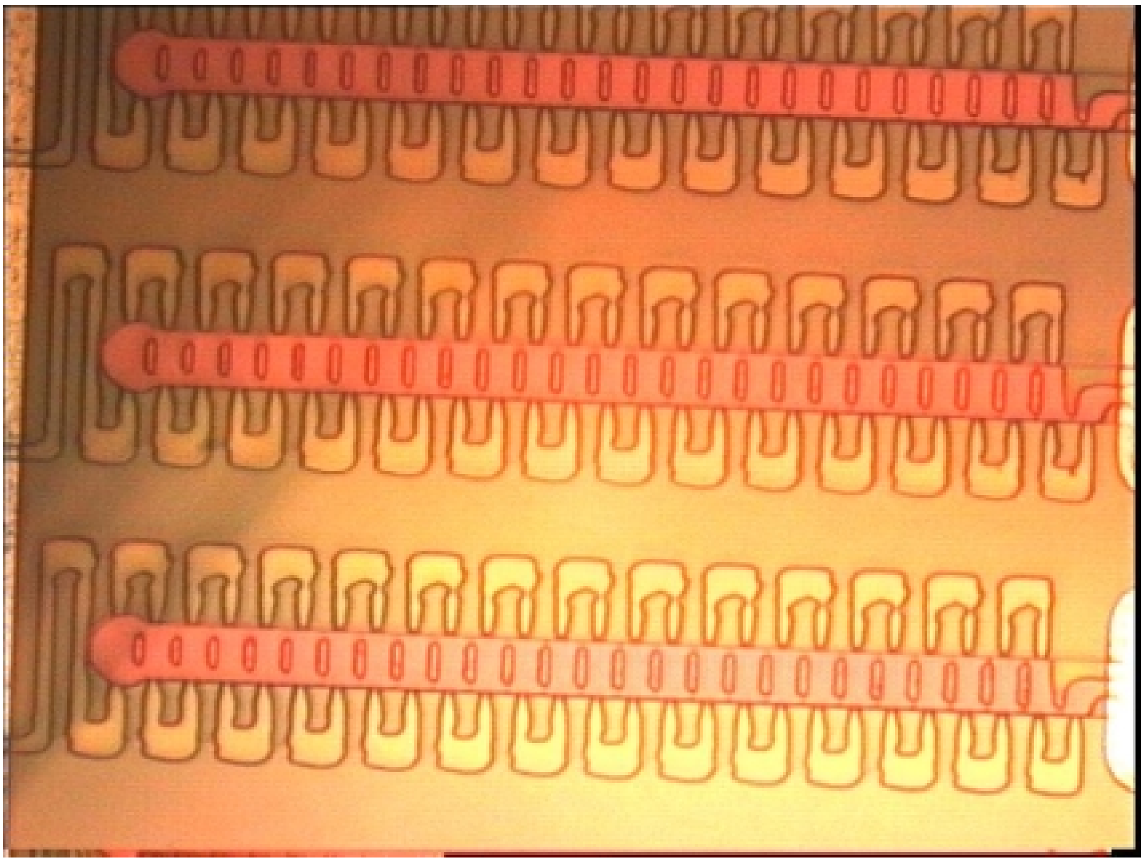
Detection of broken resistors





Detection of Resistor Process Defect

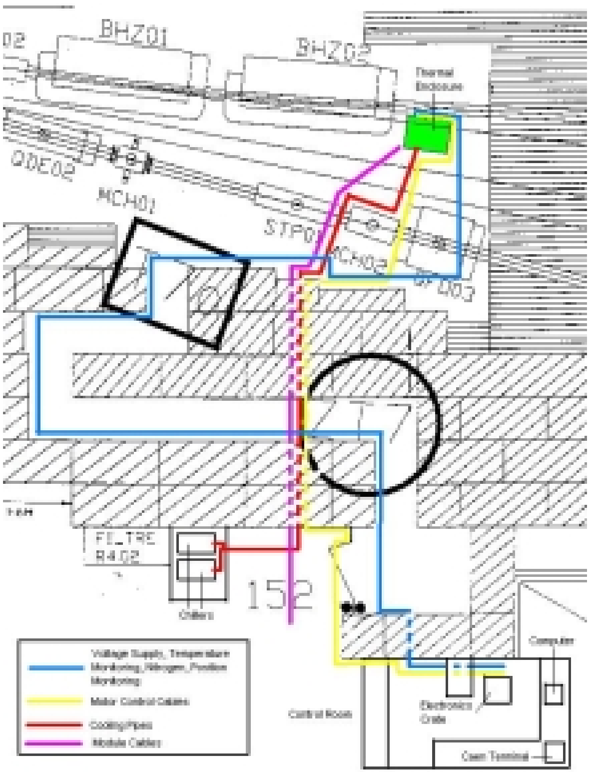




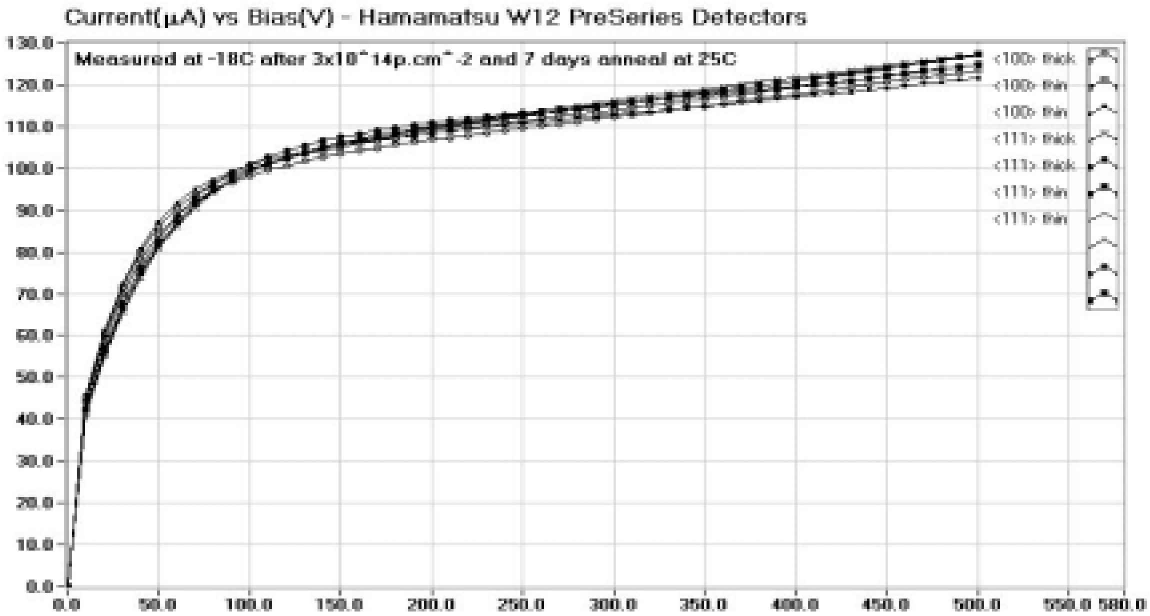
Irradiations

Samples of detectors will continue to be irradiated throughout production, to ensure that the post-irradiation performance observed from qualified detectors is being maintained.

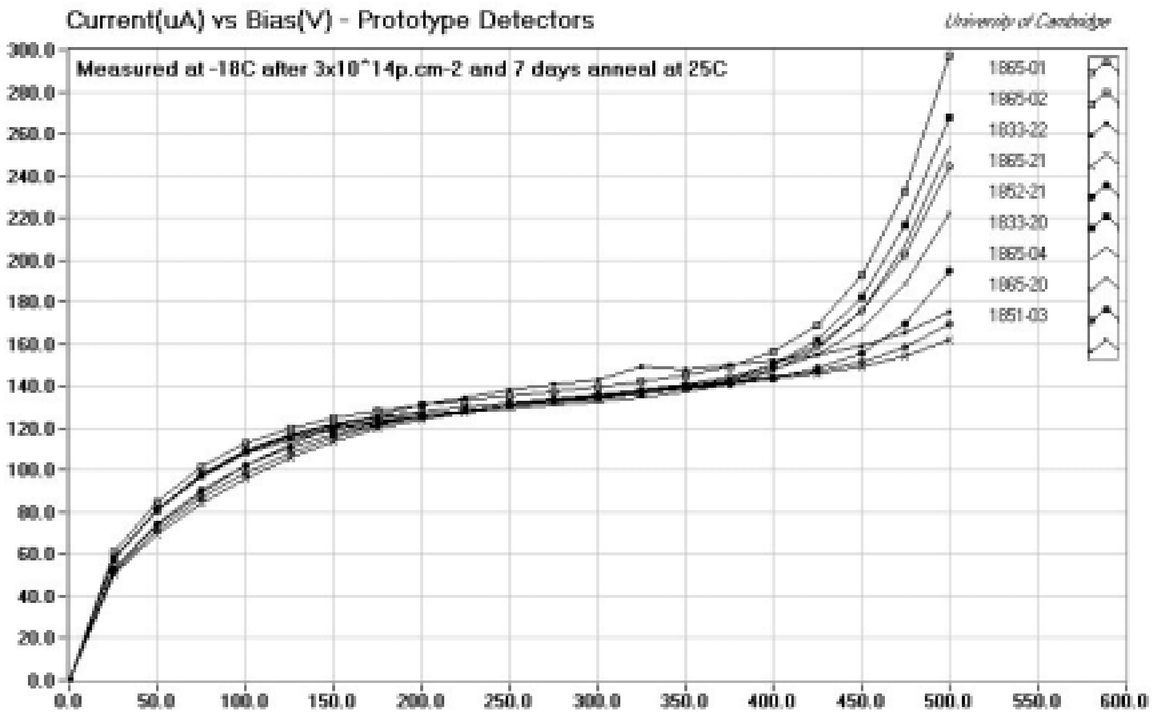
The detectors are irradiated with 24 GeV/c protons to $3x10^{14}p.cm^{-2}$ at the T7 irradiation facility at the PS. During irradiation, the detectors are chilled in nitrogen to $-8^{o}C$, and biased at 100V with all strip metals grounded. The irradiation takes typically 6-10 days, and following irradiation the detectors are annealed for 7 days at $25^{o}C$ to bring them to the minimum of the anneal point.



Post-Irradiation Leakage Currents

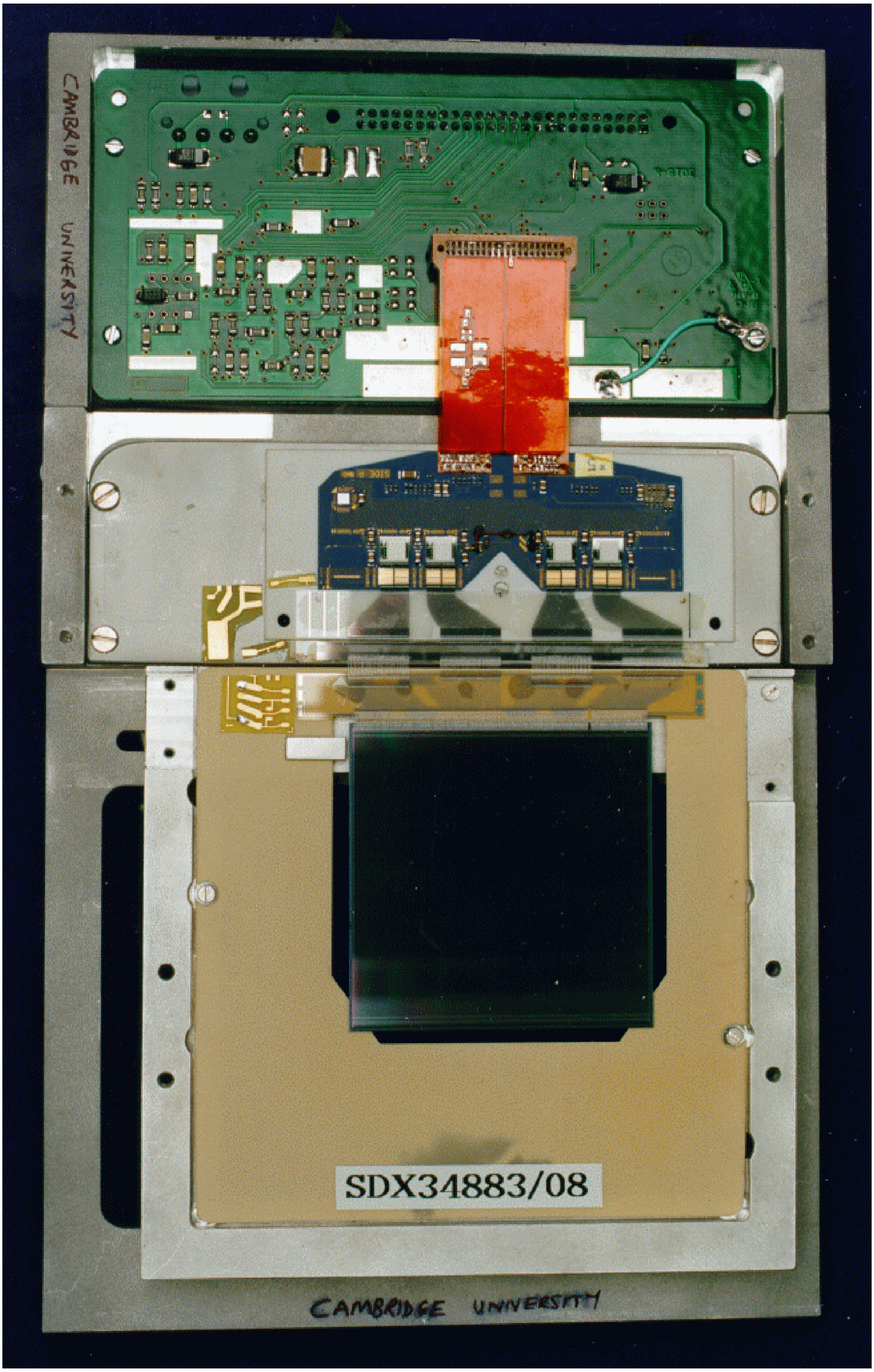


Qualification W12 detectors from Hamamatsu



Early prototypes from non-qualified manufacturer, showing current increase from 400V due to microdischarge.

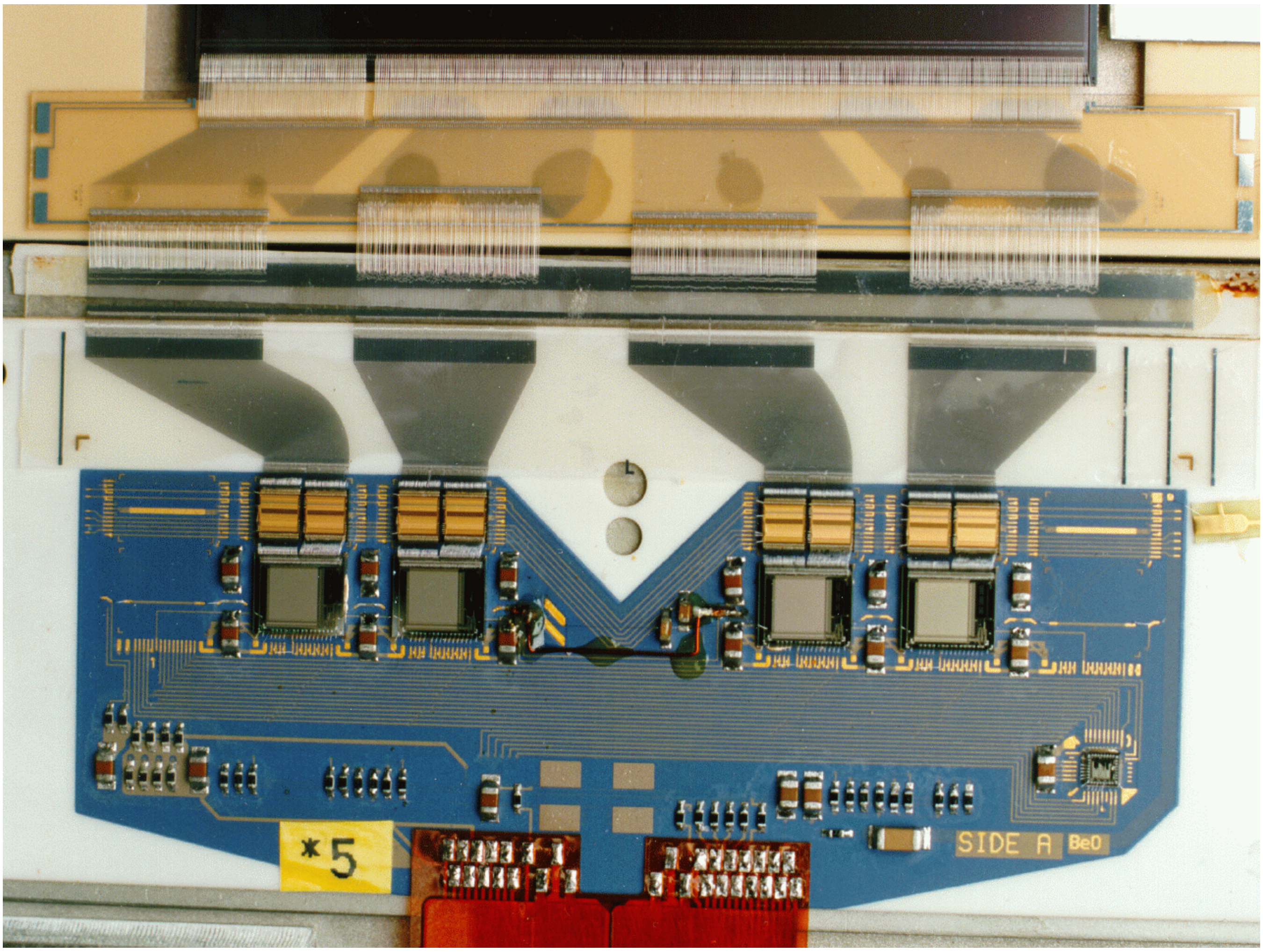
Measuring Strip Noise Distribution using rebondable modules



Detail of wirebonding scheme of rebondable binary module

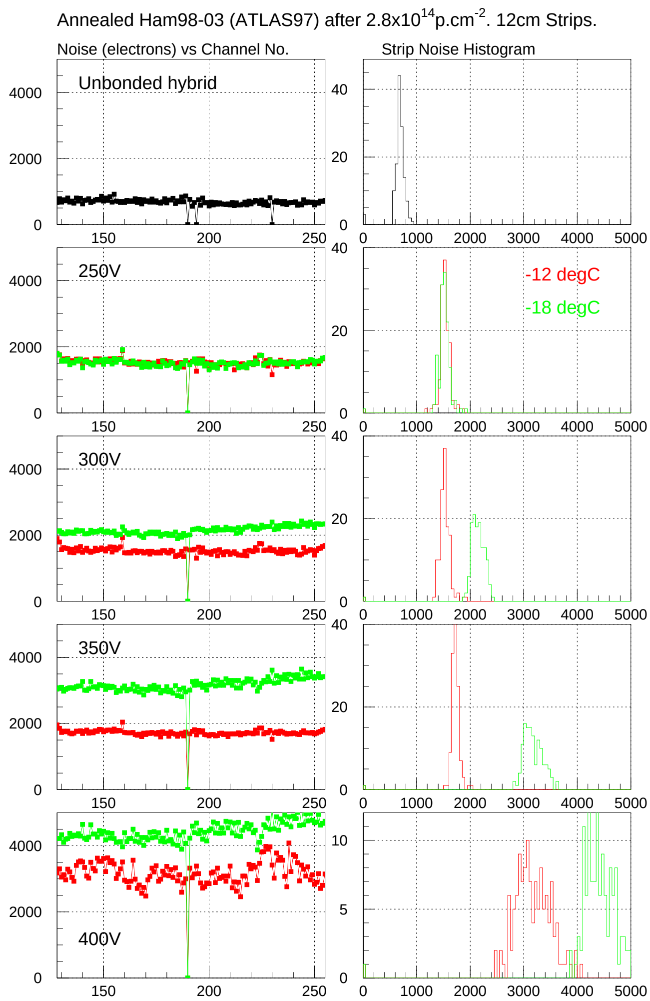
Effective strip length connected to chip:

6cm 12cm 6cm 12cm

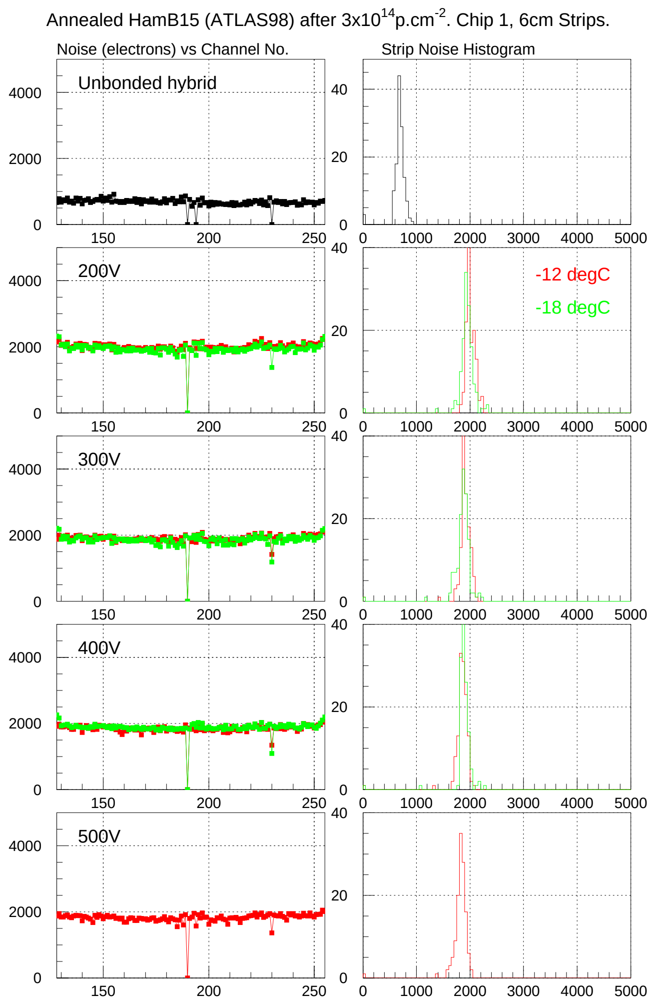


Strip Noise Distributions

Binary Readout (LBIC/CDP) at 40MHz

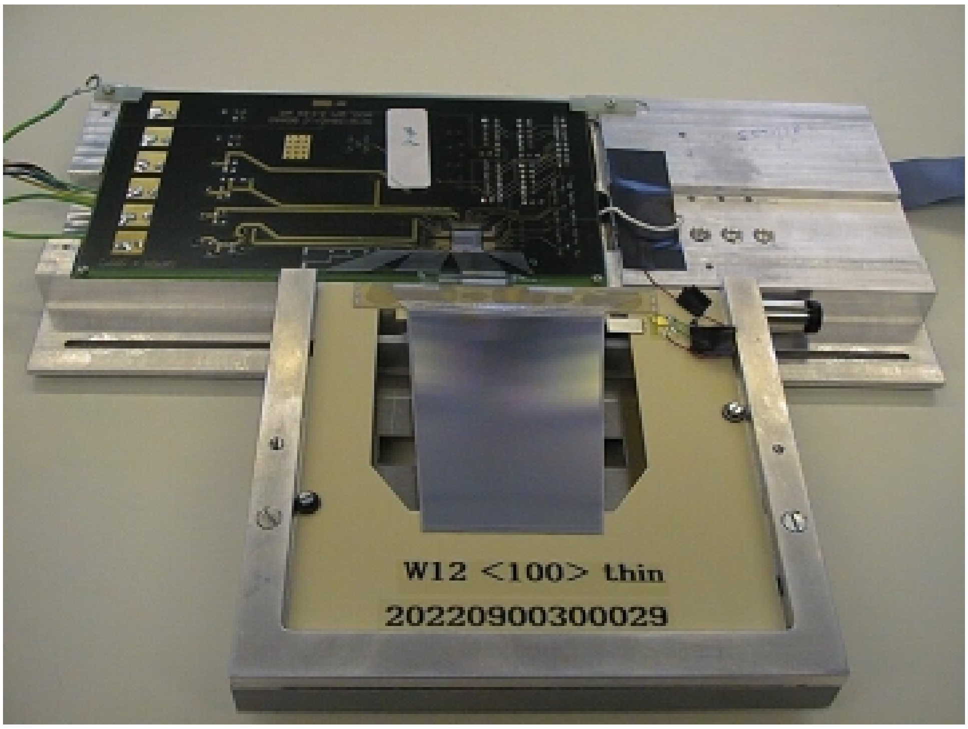


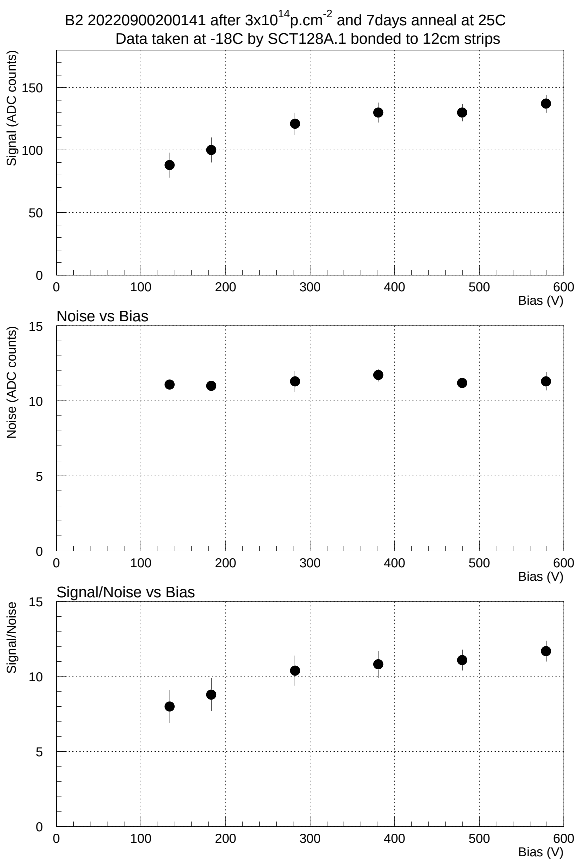
Early prototype, showing widespread microdischarge with increase bias



Detector from qualification batch, no signs of microsdischarge.

Charge Collection, using SCT128A





Either 6cm or 12cm portion of the sensor is bonded to a SCT128A analogue chip running at 40MHz. Charge measurements are performed using a Ru^{106} β-source

Summary

• The quality and robustness after irradiation of the SCT microstrip sensors has been demonstrated in a qualification program

• The QA strategy defined by ATLAS is that production sensors must use identical masks and processing as qualified sensors.

• QC procedures are now well established to check basic quality and to monitor the characteristics of production sensors in comparison to qualified sensors.

• Production is underway and (mostly) on schedule for Hamamatsu and CiS. Some further qualification tests are in progress for Sintef sensors and CiS oxygenated W12s.

• QC by the receiving institute is essential, particularly in the early stages of mass production

Eg:
- *severe edge chipping on rear side on early deliveries due to misinterpretation of specifications*
- *some subtle but severe processing abnormalities passed unnoticed by the manufacturer*
- *manufacturer is completely reliant on ATLAS for feedback on post-irradiation robustness*