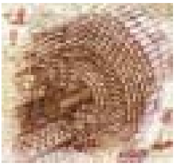


Excess leakage current and strip noise

- Focus on micro-discharge at strip edges
- Some history
  - Strip geometry optimization for
    - Safe high voltage operation
    - Low capacitance
- “Minimal knowledge” model of micro-discharge at strip edges
- Estimate of expected strip noise
- An interesting model for micro-discharge
- Expected impact of strip noise on APV behavior
- Some remarks on the possible use of IR cameras for diagnostic/screening

Optimization of strip geometry, for example, using Multi-Geometry sensors

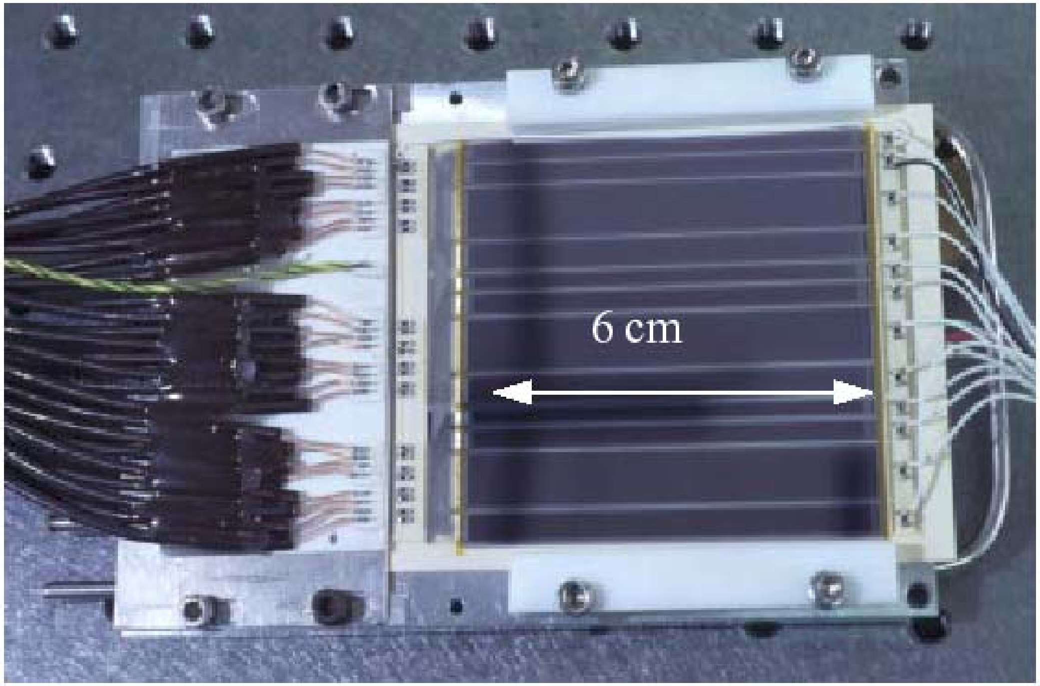


Fig. 5 A Hamamatsu multi-geometry AC detector assembled for characterization. From the left to the right: the leads to the input of the LCR meter, the measurement piece in ceramic carrying the 47 kΩ and 1 MΩ resistors, the glass pitch adaptor, the multi-geometry detector mounted on a ceramic frame and the ceramic piece with the 100 kΩ resistors for the measurement of the leakage current from the guard ring of each of the 12 subdetector regions (see also the text).

Pitch from 60 to 240μ

Vary w/p

Shallow/deep implant

With/without over metal

High/low resistivity
<111> or <100>

Systematic Study of:

depletion characteristics,

strip capacitance

& break-down voltage

Break down voltage vs. strip geometry:

deep implant better than shallow
over metal is key and dominates over implant depth

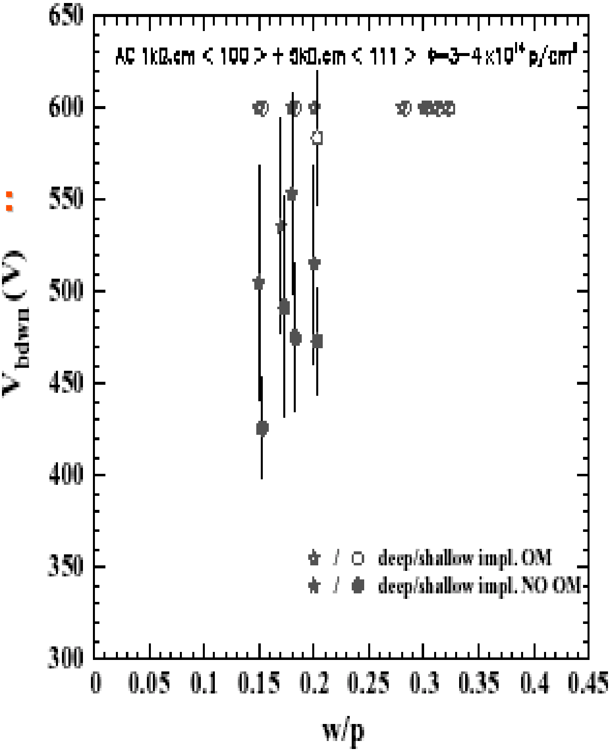
240μ pitch less robust,
so more sensitive to defects

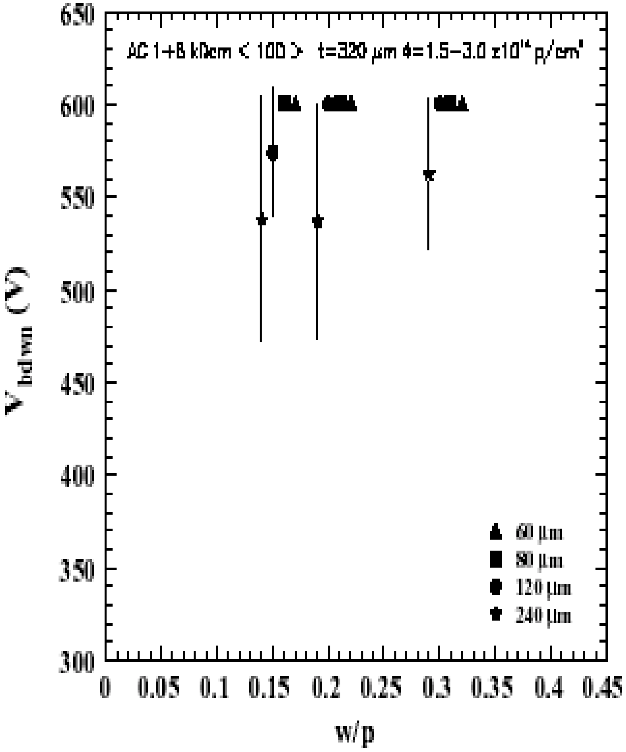
With over metal
Deep and shallow

Without over metal:

deep implant

Shallow implant





With over metal

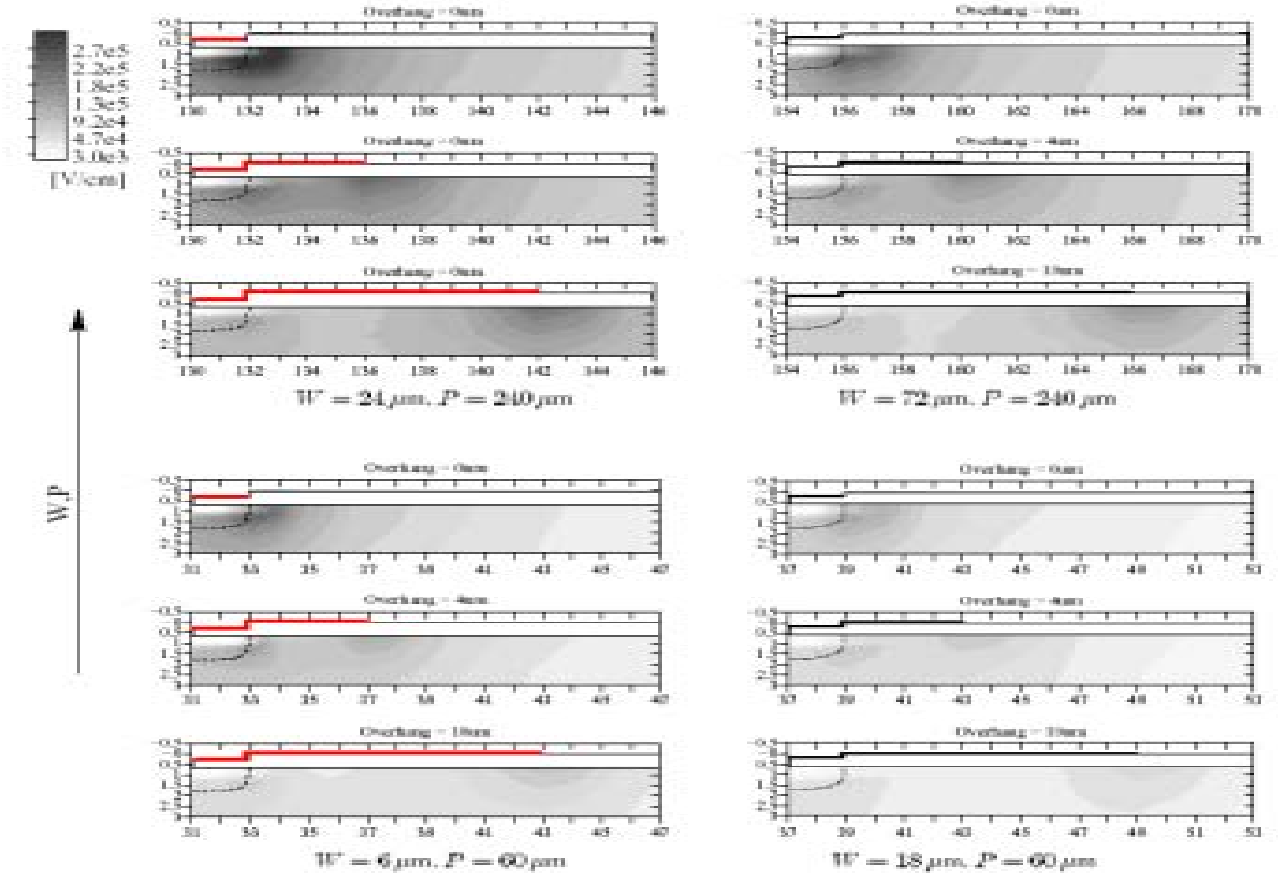
Pitch 60 to 120μ

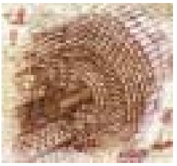
Pitch 240μ

Larger values of w/p (>0.25) are more robust

CAD field gradient calculations
(D. Passeri et al)

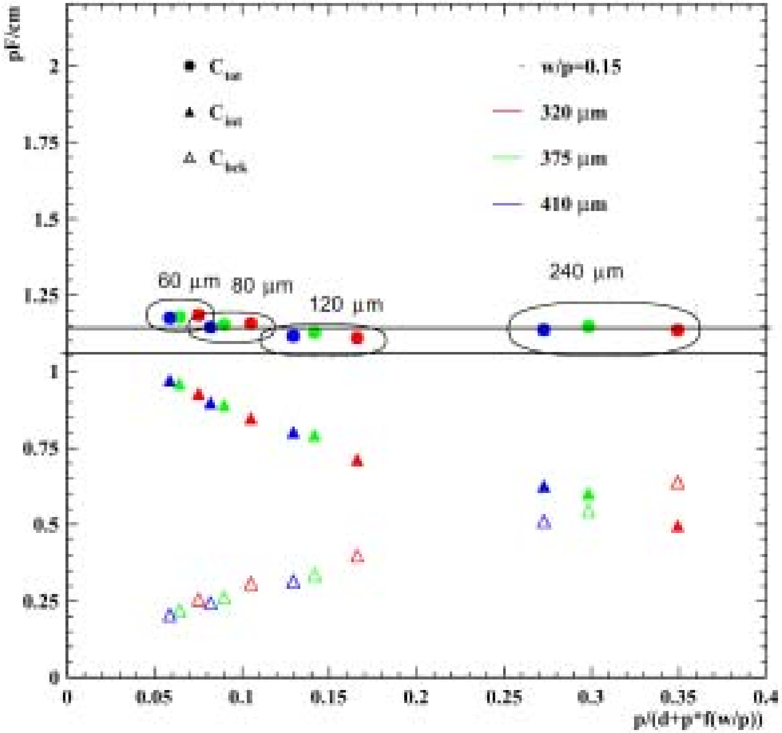
Confirm expectations for dependence on w/p, key beneficial effect of over metal
And decreased margin for 240µ pitch





Silicon Sensor Geometry

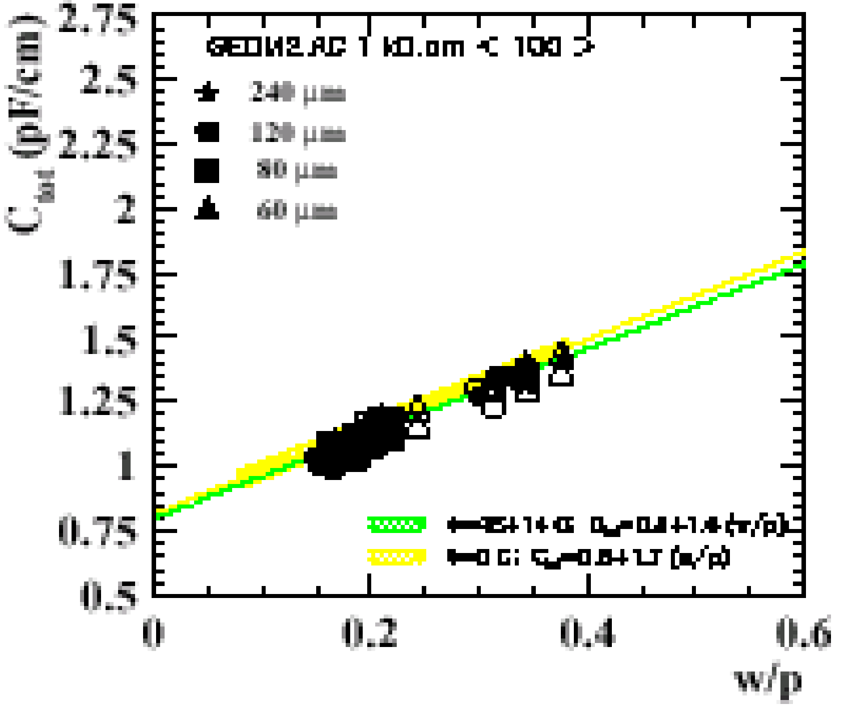
Strip capacitance ~ 1.2pF/cm for w/p = 0.25
Independent of pitch and thickness



Use 320µm thick Si for R < 60cm, Strip ~ 10cm

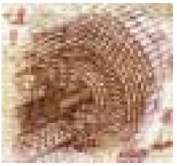
Use 500µm thick Si for R > 60cm, Strip ~ 20cm

Strip capacitance is insensitive to irradiation for <100> crystal lattice



Expected S/N after irradiation deconv

S/N ~ 13 for thin sensors, short strips
S/N ~ 15 for thick sensors, long strips



A “minimal knowledge” model of micro-discharge (was used as guideline when writing the sensor specs)

Charge is generated by break-down, or discharges, in a high field region close to the edge of an implant strip. In order to lead to the observed noise levels, the charge must be released in packets every so often.

This model is not very predictive: the character of the noise and its dependence on the excess current can only be established empirically.

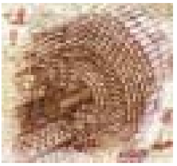
The time structure of these packets is a-priori unknown, the only constraint being that the current must average to observed value over sufficiently long times. This allows some limits to be put on worst case scenarios, as will be seen below

In such a model, at very low discharge rates the noise will have two components:

A Gaussian similar to that of normal strips, if no discharge within the 25ns sample

A spectrum of “noise hits” due to discharges within the 25ns sample

The normal Gaussian will rapidly disappear as the rate of discharges within a 25ns sample increases appreciably above 1.



A “minimal knowledge” model of micro-discharge

To set the scale for the possible effect of the noise, consider the (arbitrary) scenario that charge is released in ~ MIP like packets (~40’000e- in thick sensors)

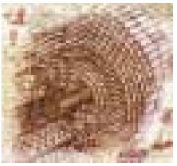
The discharge rate, or “noise MIP” occupancy, will vary linearly with the current, eg from

Excess current = 2.5nA “noise MIP” occupancy ~ 1% (normal Gaussian noise 99%)

To

Excess current = 250nA “noise MIP” occupancy ~ 100%

This explains why strips with excess leakage current above 10nA are a cause for concern, and why strips with current above 100nA are considered defective, according to our specifications.



Expected effect of excess single strip noise on APV behavior

The recent observations on TOB modules are that strips with excess leakage current between about 1 and 10microAmpere can seriously degrade the performance of an entire APV.

With such currents, the maximum packet size which could be released on average once every 25ns, for example, ranges from 4 to 40 MIP's equivalent with the resulting noise multiplied by the corresponding Poisson statistics

This is a worst case scenario, in the sense that the estimated noise decreases rapidly as the assumed rate of discharges increases and their amplitude decreases accordingly

In the absence of saturation, a single strip noise at this level would result in a CM across the APV ranging from a fraction of a MIP up to of order 1 MIP's equivalent:

- a significant, and certainly undesirable, degradation, but nevertheless a manageable one.

However, the saturation mentioned above may well have an important effect on the performance of the APV as whole.

In the above scenario, the noise for strips drawing between 1 to 10μA spans the range over which the APV can be expected to go from a linear to a saturated response

An interesting model for micro-discharge

A thermally generated primary charge (bulk leakage current) arriving in the defective high field region, will undergo multiplication by a very large factor (eg APD), and will thereby trigger a discharge

To set the scale, let us assume that the region over which the micro-discharge takes place presumably has a size of order the strip pitch, say 100μ, both longitudinally as well as transversely

Since a strip draws typically 1nA over its full 10cm length, then the local bulk leakage current is of order 1pA.

This translates to about 6e-/μs, or about one in every six 25ns samples, leading to a 15% occupancy of discharges driven by bulk current amplification

Assuming all discharges are driven in this way, the typical discharge amplitude will range from ~25 to 250 MIP's for excess strip currents of 1 to 10μA respectively, so that the APV would be strongly saturated by each discharge

An interesting model for micro-discharge

The assumption that all discharges are triggered by bulk current multiplication leads to some distinctive features:

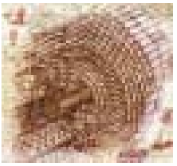
It predicts a "low" occupancy of very large noise hits, with a Poisson statistics, with a large fraction of samples being unaffected by the noise (at least in the regime where the APV is not saturated)

The rate of discharges should have the same exponential temperature dependence as the normal bulk leakage current, since this is what is assumed to triggers the discharges

The amplitude of the discharges should not vary with the temperature

The rate of the discharge should not vary with bias voltage, since the bulk current is substantially insensitive to this, but the amplitude of the discharges should be proportional to the excess strip current

With so much to go on, it should be possible to see to what extent this assumption may be valid



IR camera as diagnostic/screening tool for leaky strips?

Required sensitivity:

For diagnostic work (localizing a defect along a known bad strip) ~< 1μA

For sensor screening ~< 100nA

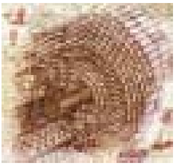
- (since above ~ few hundred nA can spot problem from kink in total IV curve)

Back of the envelope: local ΔT for micro-discharge =100nA(1μA), at 500V, assume constant heat dissipation over the full depth of sensor, ~1.5(15)mK

Finite element calculation ~1.1(11)mK (M. Oriunno): a strong lower limit.

Infact, the power dissipation is not homogeneous, as the field is highest at the strip implants, and decreases towards the back-plane.

Assuming all the power is dissipated in the 40μ below the strip, the local temperature increase is ~5(50)mK. This is probably a high estimate.



IR camera as diagnostic/screening tool for leaky strips?

Sensitivity of commercial cameras:

For ~ 10KEuro standard sensitivity ~ 80mK 1σ noise equivalent

For ~ 50KEuro standard sensitivity ~ 20mK 1σ noise equivalent

50KEuro camera may be just ok for diagnostic, not for screening

Furthermore need about 1:1 projected camera pixel size on target to match size of micro-discharge region, which requires adapter rings

Still under investigation:

how much can sensitivity be improved by averaging of multiple measurements?

Caution: even if possible in principle, this would be an “exotic” use of the IR camera, which would certainly require significant development time and effort