R&D paths of pixel detectors for vertex tracking and radiation imaging

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This report reviews current trends in the R&D of semiconductor pixellated sensors for vertex tracking and radiation imaging.

Requirements and R&D perspectives

- The main purpose of Si pixel sensors in collider experiments is the accurate reconstruction of the trajectories of charged particles in the proximity of the beam collision point.

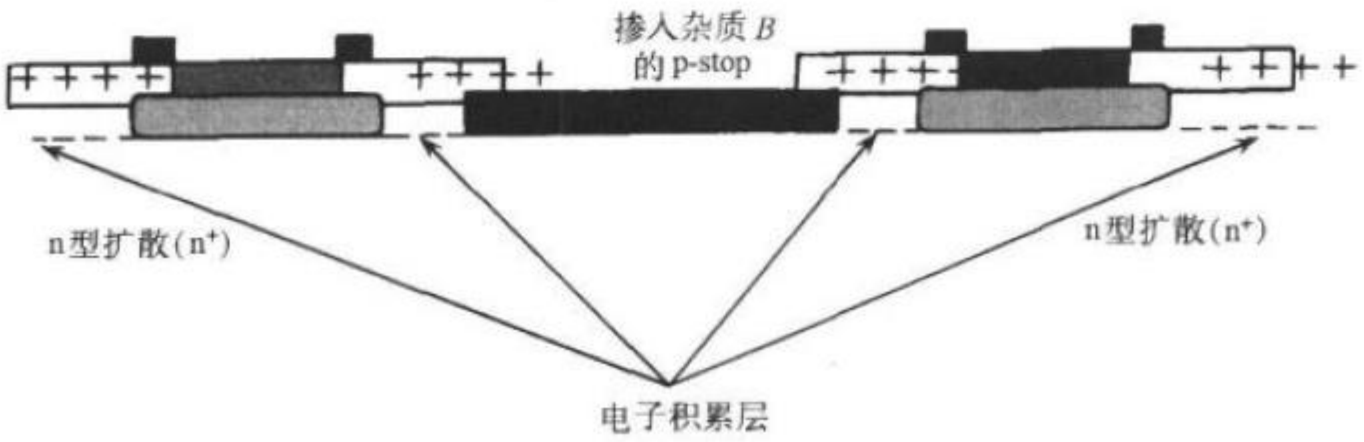
- The ability to reconstruct the sequence of primary, secondary and tertiary vertices depends on the impact parameter resolution.

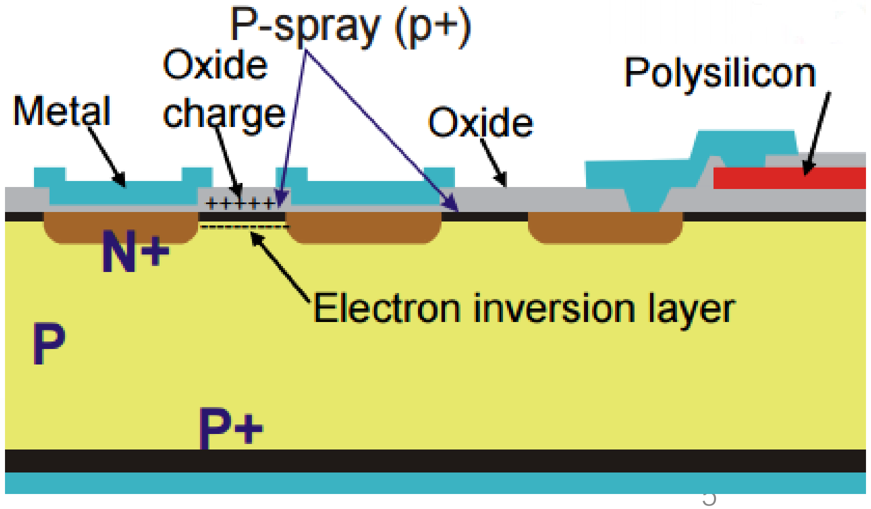
- Impact parameter $\sigma_{IP} = a \oplus (b/p \sin^k \theta)$, defined as the distance of closest approach of the particle track to the colliding beam position. p is the particle momentum, θ the track polar angle and k¼3/2 for the R−Φ and 5/2 for the z projection.

Radiation hardness

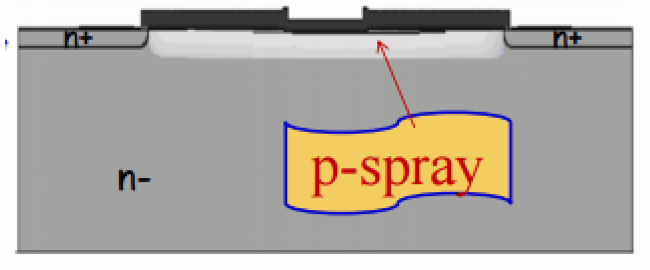
- At hadron colliders the location of the detector closest to the collision point depends on the radiation levels and their effects on the sensors and readout electronics.
- Radiation effects in silicon detectors can be distinguished in two main categories. ionising and non-ionising effects.
- Ionising radiation affects the surface oxide layers of sensors and electronics with the creation of conductive electron accumulation layers, lateral isolation oxides of MOSFET transistors and buried oxides in SOI devices. its effects are present as well in vertex detectors at colliders.
- In sensors, these can be compensated by the deposition, under the oxide, of a p-doping layer commonly called p-spray.

- Non-ionising radiation effects consist in damage to the crystal lattice of the Si bulk and its primary consequence is the generation of defects in the material .
- Question from Tao: why conductive electron accumulation layers are created on surface oxide layers after ionising radiation
- This paper doesn't show where the conductive electron accumulation layers are, I think the condition depends on the electric field of the sensor





- Question from Xin: “In sensors, these can be compensated by the deposition … “ How does this happen?
- The “deposition” means p-spray, it can insulate strips and prevent short circuit effect caused by the conductive electron accumulation layers



Hadron colliders

- The radiation levels at hadron colliders increase with luminosity and decrease with the radial distance from the beam.
- At present, the most effective way to improve the radiation hardness of Si sensors is by engineering their geometry to allow the highest possible electric field to be applied across their sensitive region .Other materials, like diamond, could also be considered for their better noise performance.

Pixel pitch

- The two main drivers for the sensor pixel pitch, P, are the single point resolution, which scales as P and the local occupancy, which scales as the pixel area (i.e. $\propto$P2 for square pixels) times the readout time.
- At collider experiments, the single point resolution has played so far a major role in determining the pitch of microstrip detectors adopted at LEP and the pixel size of the CCD at SLC .

- The availability of thin sensors is important to precision vertex tracking
- Much thinner active layers can be afforded by monolithic CMOS and DEPFET technologies, DEPFET sensors can be thinned to <100 μm in the sensitive region

- Question 1 from Ryuta: "DEPFET" is mentined in the paper several times, how the DEPFET works as a pixel sensor ?
- DEPFET is Depleted P- Channel Field Effect Transistor, It is based on the sideward depletion as used in the semiconductor drift chamber and the field effect transistor which can be of MOS-type or junction type. The transistor is located on top of a low-doped n-type semiconductor substrate. It becomes fully depleted by applying a sufficiently high negative voltage to the backside p+ contact.

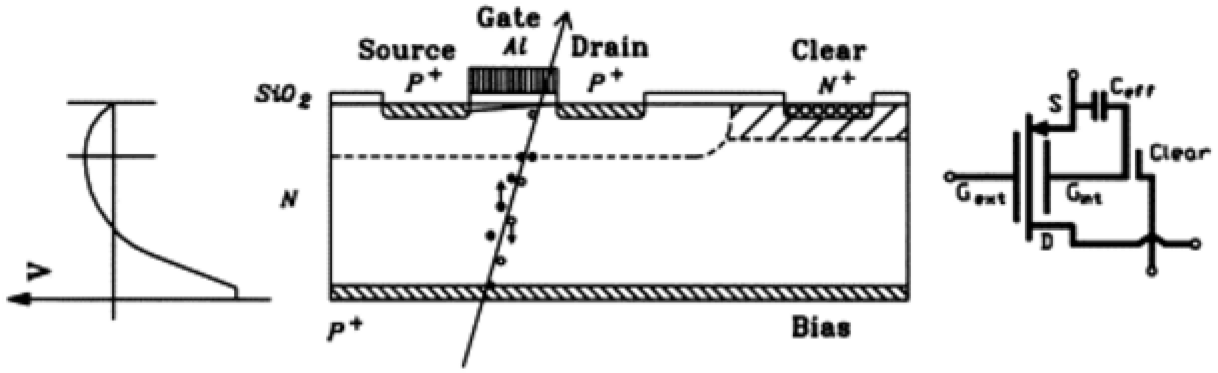


Fig. 1. The DEPFET structure and device symbol.

- http://twiki.hll.mpg.de/bin/view/DEPFET/DepfetPrinciple

- Question 2 from Ryuta: What might be superior point of DEPFET over the CMOS sensor what we are usually talking about, or on the contrary, what might be superior point of the CMOS sensor over DEPFET ?
- DEPFET's superior point:

High granularity pixel detectors, low multiple scattering, thin detectors, avoidance of cooling of sensor, low power consumption, limitation of occupancy, sufficiently high readout speed

- In the future, for thin oxides gate leakage and voltage swing become a concern, particularly for monolithic CMOS active pixels. 3D integration of two or more vertically interconnected layers of CMOS circuits promises to help by shortening connection paths and by increasing functional density

- The emergence of monolithic pixel sensors from the late nineties was driven by the necessity to reach material budget and granularity performances well beyond the current LHC standards, combined with the capability to cope with high hit rates.
- This is being exploited in the design of new pixel systems where advanced functions can be performed in the circuitry implemented in each pixel to provide the required signal-to-noise ratio and to handle the high data rate. These functions include amplification, filtering, calibration, discriminator threshold adjustment, zero suppression (also called data sparsification) and time stamping.

- Question from Hao: what is the "thin oxides gate leakage" and "voltage swing"? Why do they became a concern for CMOS active pixels?
- I don’t know.
- Question from Maoqiang: what do zero suppression(also called data sparsification) and time stamping refer to?
- time stamping may refer to time resolution .

Conclusion

- The future of sensors for vertex tracking seems to belong entirely to pixellated sensors with point resolution $\leqslant 10\ \mu m$, time resolution of the order of few to 25 ns and tolerant to ever increasing radiation levels.

Thanks!