The Open University

Sensors with Fast Charge Collection

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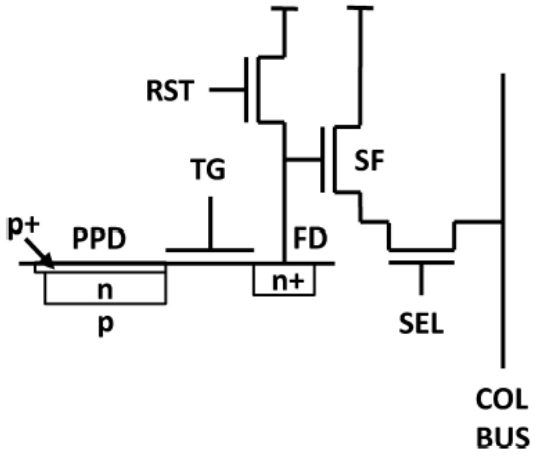
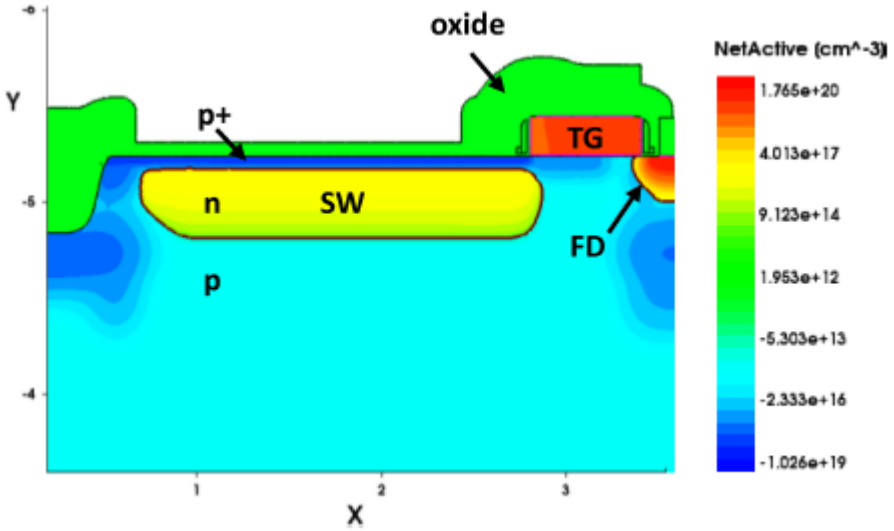
Introduction

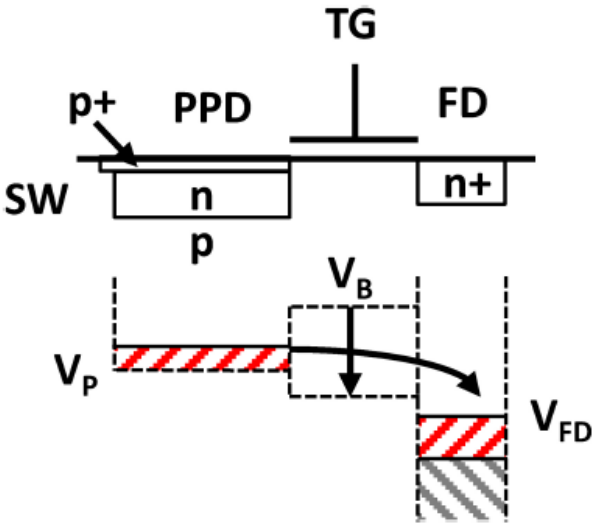
- The Silicon Pixel Tracker (SPT):
  - The main driver is low detector mass
  - Low mass is enabled by low detector power
  - Further helped by reduced cooling, cables and mechanical structure
- Low power, low noise, large pixel sensors
- Pinned photodiode (PPD) pixels are promising
  - Large pixels possible (100 µm reported)
  - Charge collection is separate from charge-to-voltage conversion – allows large voltage signals, a requisite for low power dissipation
  - Prompt charge collection, if the sensitive detector layer is fully depleted
  - Charge transfer to the sense node is relatively slow, but there are new developments

Pinned Photodiode (PPD)



- Also known as 4T pixel
- Widely used in imaging CMOS sensors with excellent performance
  - Responsivity ~100 µV/e-, large voltage signal
  - Noise could be ~1 e- RMS
  - Correlated double sampling comes naturally
- Not used in HEP (yet)

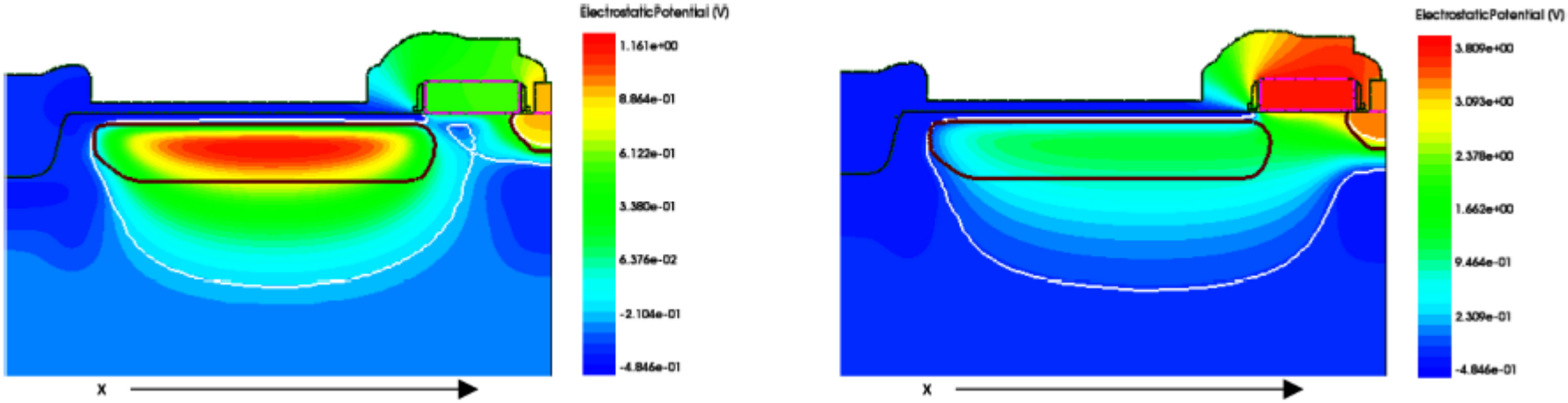




Eric Fossum, IEEE Journal of the Electron Devices Society (2014)

PPD Operation

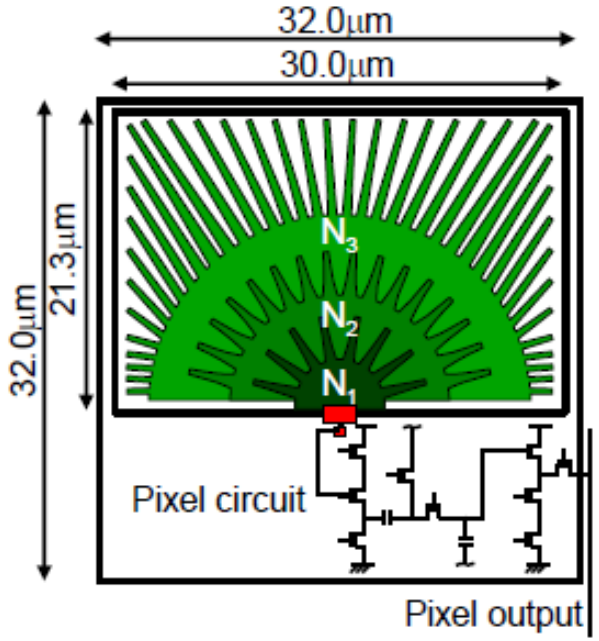
Eric Fossum, IEEE Journal of the Electron Devices Society (2014)

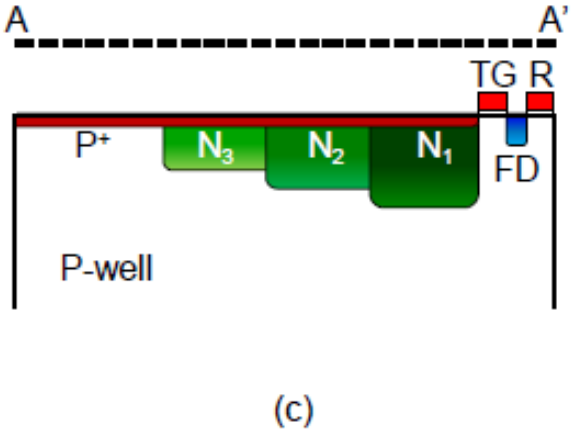


- **Similar charge transfer happens in CCDs, but here without much electric field**
- **Charge transfer is slow (few µs)**
  - **Not a problem for an integrating tracker**
- **Large pixels (50-100 µm) are a solvable challenge**
- **Full depletion possible too**
- **Large PPD pixel enabling integrating tracker could be a very strong proposition**

Accelerated charge transport in PPD

K. Miyauchi et al., Proc. of SPIE-IS&T/ Vol. 9022 902203-1

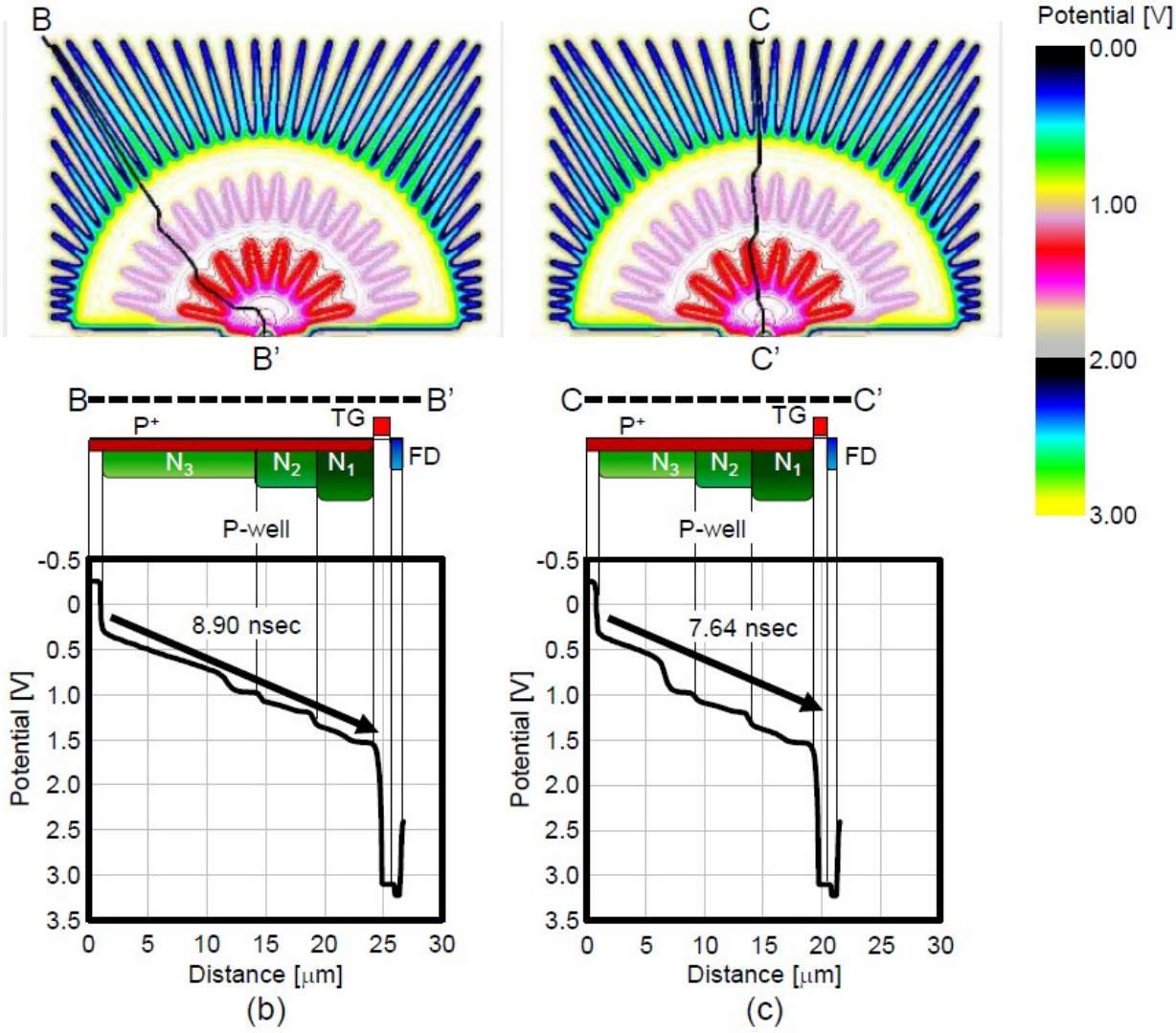




- **Increased diode doping concentration towards the sense node (FD)**
- **Higher doping causes higher potential**
- **Creates potential gradient towards the sense node**
  - **Electric field is small (500 V/cm), but enough to make a difference**

Performance

- Charge collection of 96% in 10 ns due to the large depleted diode
- Charge transfer within PPD below 10 ns
- 32 µm pixel used for high speed imaging
- 20M frames per second achieved in burst mode
- Similar approach can be used to speed up larger pixels (~100 µm)



Conclusions

- A solution to the slow charge transfer in PPD pixels has been presented
  - Remains to be seen how it will behave for SPT-sized pixels (50-100 µm)
  - Avenue for further work
- In the near future (2-5 years), the following developments are expected:
  - Fast charge transfer in large pixels (50-100 µm) – nearly there
  - Fully depleted PPD pixel with thick sensitive layer (> 50 µm)
  - Both do not allow full CMOS logic in pixel – not a showstopper for slower detectors, or if no processing in pixel is acceptable
- In more distant future (>5 years):
  - Fully depleted, fast and large PPD allowing full CMOS logic in pixel
  - First ideas are appearing