EUROPRACTICE Microelectronics tools at University of Zurich for DAMIC-M & CMS

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Introduction

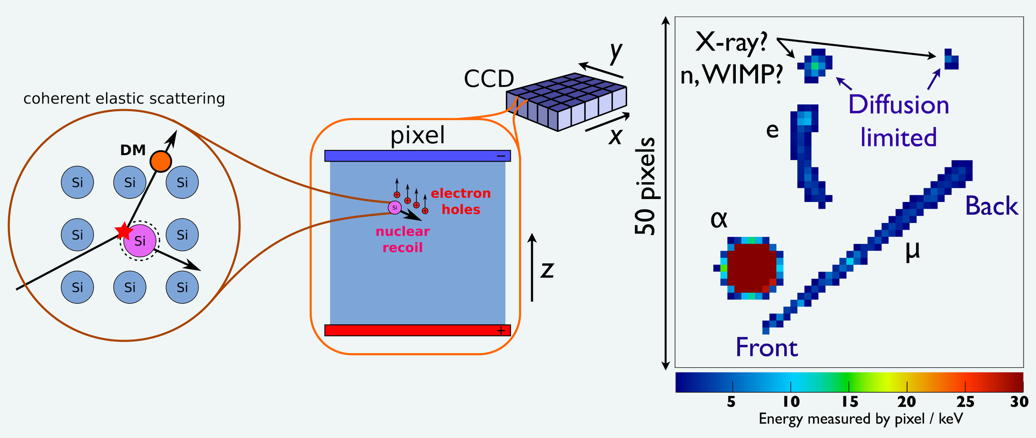
The Physics Institute of University of Zurich (A16440) has become a EUROPRACTICE member as of early 2019. There are two active research projects within the institute that are using the tools provided by EUROPRACTICE Microelectronics:

- The DArk Matter In CCDs (DAMIC) collaboration is currently using tools from Synopsys to perform device simulations. (S. J. Lee (stelee@physik.uzh.ch), Prof. B. Kilminster, et. al.)
- The Compact Muon Solenoid (CMS) collaboration is currently using tools from CADENCE to develop silicon pixel sensors. (Dr. A. Macchiolo, Prof. B. Kilminster, Prof. F. Canelli, et. al.)

In addition, the institute is looking for the fabrication capability of CCD sensors provided by EUROPRACTICE on behalf of the DAMIC-M collaboration.

DArk Matter in CCDs (DAMIC)

DAMIC is a silicon target experiment which utilizes Charge Coupled Devices (CCDs) with ultra-low leakage current developed by Lawrence Berkeley National Laboratory (LBNL) and produced by DALSA. In the underground labs in SNOLAB, an array of these CCDs was installed in ultra clean and ultra radio-pure environment in an effort to search for dark matter candidates.

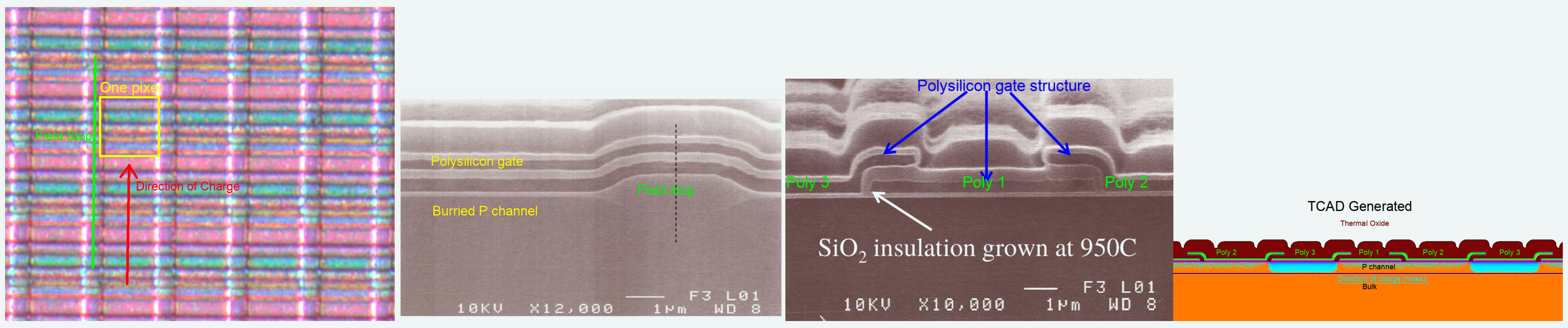


From left to right: illustration of dark matter interactions in silicon target and reconstructed particle tracks observed by DAMIC-SNOLAB CCDs[1].

To improve the detection efficiency, TCAD is being used to optimize the CCD operation parameters and to simulate the effects of the defects and impurities embedded in the target. The next generation detectors will be installed at Laboratoire Souterrain de Modane (LSM) by the DAMIC-M collaboration. For more information please visit https://damic.uchicago.edu/.

Synopsys Sentarus Technology CAD for device simulation

LBNL has developed specialized fully depleted back-illuminated CCDs which can operate at low temperature (135 Kelvin) and at low pressure (10^{-7}mbar) which is ideal for minimizing thermal effects and dust. The DAMIC-M collaboration will use 650μm-thick 3-stage high voltage (40V) fully depleted CCDs with skipper amplifiers.



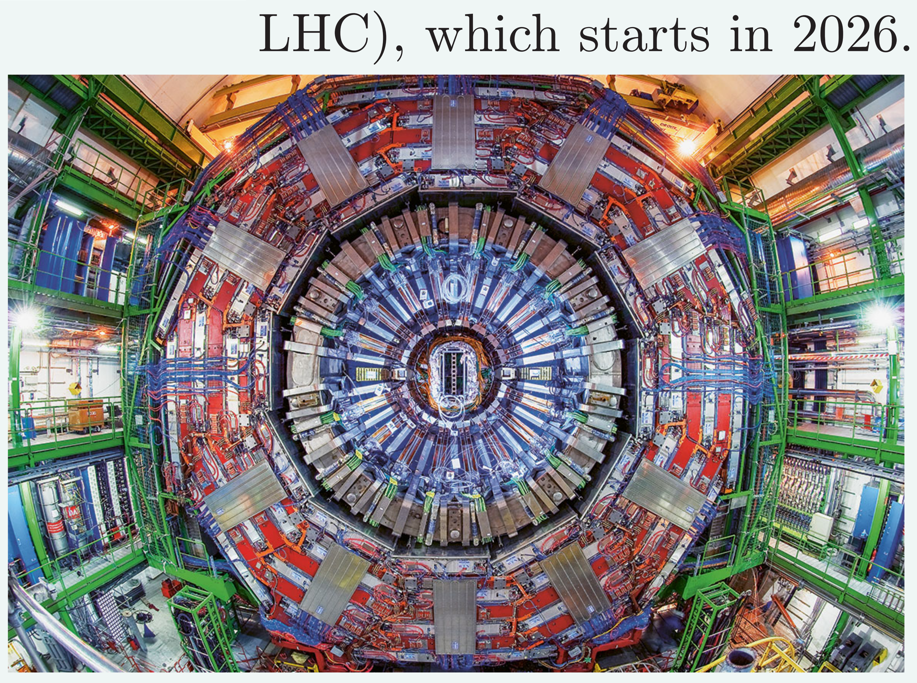
From left to right: Gate structure as seen from the front surface of the CCD, TEM of the field stop structure between columns[2], SEM of the gate structure[3] and TCAD generated gate structure and following hole density during read operation.

One of the disadvantages of using the CCDs as sensors is asymmetry in its pixel structure. Furthermore to perform the readout of an individual pixel, a sequence of electric potentials (called sequencer) needs to be sent to the device. Using TCAD, we can create a simulated device and study its properties. Some examples are below:

- As charge charge carriers diffuse in the bulk of the device, we can simulate the asymmetric fields. This can help reconstructing the asymmetric particle tracks and correct them.
- Using the device simulations, we can also study the size of the potential well in an individual pixel. We can use then this information to optimize the sequencer to minimize the excess potential minimizing the readout noise.
- Charge traps can be placed in the simulated device to better understand the defects and its effect in the overall operation of the CCD.

Compact Muon Solenoid (CMS)

CMS is a general-purpose particle detector located along the Large Hadron Collider (LHC) at CERN. CMS will undergo an upgrade to accommodate for the High Luminosity LHC (HL-LHC), which starts in 2026.

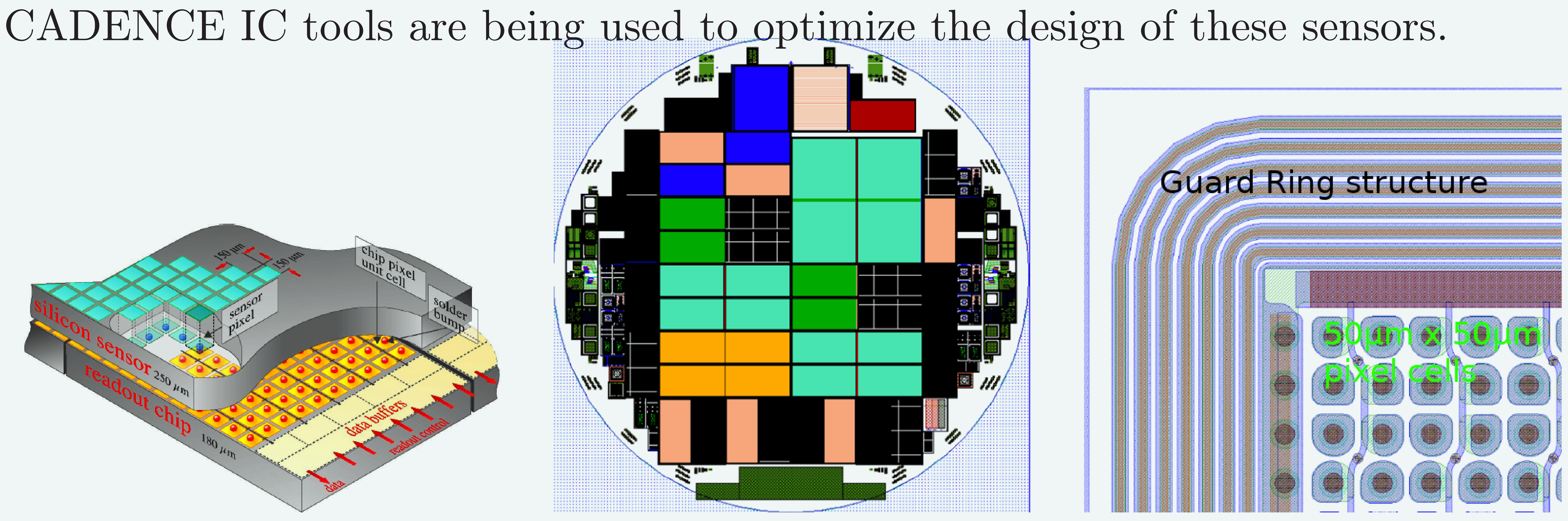


Compact Muon Solenoid[4]

To improve on the existing design of the silicon pixel sensors, CADENCE IC is being used. For more information please visit https://cms.cern/.

CADENCE Integrated Circuit for silicon sensor development

The CMS Tracker Detector is comprised of hybrid detector modules which employ silicon pixel sensors. CADENCE IC tools are being used to optimize the design of these sensors.



From left to right: Diagram of a single unit of CMS Tracker hybrid detector module[4], the mask layout (made using CADENCE IC) for the full 6" and 8" Float Zone (FZ) high resistive wafers that are used for sensor production and the layout of the pixel silicon sensor.

Some examples of sensor design optimizations include:

- Designing sensors such that they are fully depleted at low bias voltage while maintaining low leakage current.
- Designing sensors which have a high charge collection efficiency (CCE).
- Designing sensors that are radiation hard.

References

[1] A. E. Chavarria *et al.*, "DAMIC at SNOLAB," *Phys. Procedia*, vol. 61, pp. 21–33, 2015.

[2] Holland, Stephen E. et al, "High-voltage-compatible, fully depleted CCDs," *SPIE*, 05-15-2006.

[3] Steven Holland, David Schlegel/ LBNL. Cosmic Visions Workshop: Dark Energy Lawrence Berkeley National Lab Nov.14 - 15, 2017. Germanium CCD R&D.

[4] The CMS collaboration. (Accessed on 30 Oct. 2018) Compact Muon Solenoid. [Online]. Available: https://cms.cern/