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High-density and low-background Silicon packages for kg skipper-CCD instruments

The next generation of skipper Charge Coupled Device (skipper-CCD) experiments for rare-event searches will bring new challenges for the packaging and read-out of the detectors. Scaling the active mass and simultaneously reducing the experimental backgrounds in two orders of magnitude will require a novel high-density Silicon-based package, that must be massively produced and stored. In this work, we present the design, first production, and testing of multi-channel Silicon packages with photon shielding, along with the outlook for the next steps towards producing 1500 wafers that will add up to a 10 kg skipper-CCD detector.

1. Skipper-CCDs for dark matter search

Direct detection in silicon:

· SENSEI at SNOLAB: 100 g + 5 dru
· DAMIC-M at Modane: 1 kg + 0.1 dru
· OSCURA at SNOLAB: 10 kg + 0.01 dru

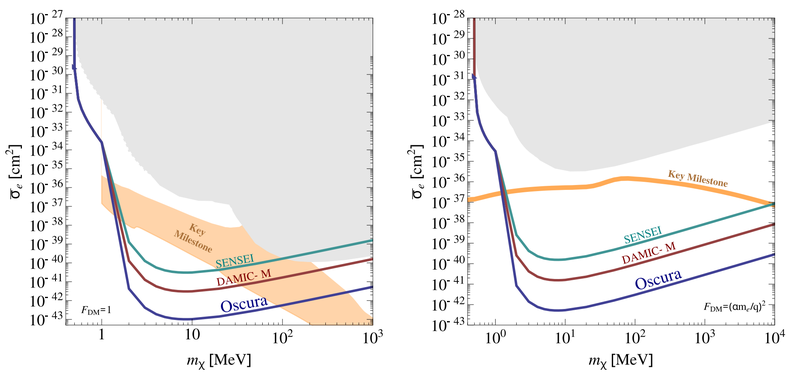

Figure 1: expectations for sub-GeV dark-matter detection with skipper-CCDs and current limits (gray shadows) for light (left) and heavy (right) mediators (adapted from referenc

2. The OSCURA package

10 kg skipper-CCDs:

· 24000 channels/devices (28 GPix)
· 1500 multi-chip modules (MCM) with 16 CCDs each
· 94 super modules with 16 MCMs each

Read-out:

· High-density package
· Multiplexer + SENSEI electronics
· ASICs

Background goal (0.01 dru):

· Silicon based pitch adapter
· Aluminum shielding
· Low-background materials

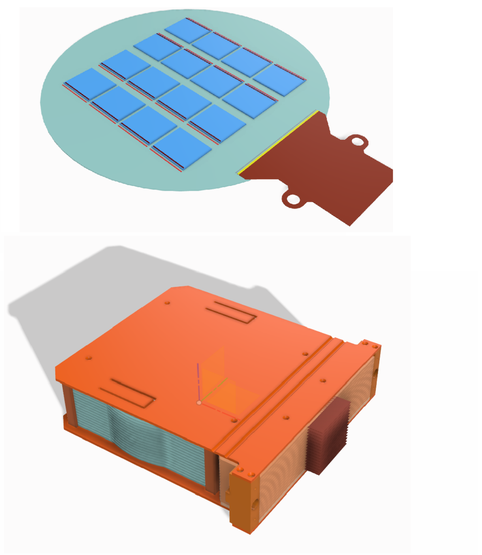

Figure 2: (Top) Design of the Oscura MCM. (Bottom) Oscura Super Module with 16 MCMs supported and shielded with electroformed copper (extracted from reference).

3. MCM Prototype fabrication at Argonne National Laboratory

Insulation layer:

· AJA dielectric sputtering system at 400◦C
·390 to 6000 nm SiO2
· Or thermal growth for 3 to 6 um SiOx

Aluminum layer:

· AJA Metal sputtering system
· 480 to 1000 nm Al on SiO2
· 1um SPR-955 + Heidelberg MLA 150
· CD-26 developer + Al Type-A wet etcher

Passivation layer:

· AJA dielectric sputtering system at 275◦C
· 450 to 1000 nm SiO2
· 1um SPR-955 + Heidelberg MLA 150
· Oxford Plasmalab 100 dry etching
· e3511 ESI Plasma Asher (EOP)

Figure 3: Silicon wafer during production. (a) SiO2 deposition (b) Aluminum deposition (c) Photoresist spin (d) lithography and development. (e) aluminum etching (f) SiO2 etching.

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4. Assembly at FNAL

Tools developed for assembly and testing at FNAL

Assembly Process:

· Glue flex cable with laminate
· Glue CCDs with EPoxy
· Wire bonds

Testing:

· Electrical (shorts and impedance)
· Reverse bias
· Cold (with multiplexed electronics)

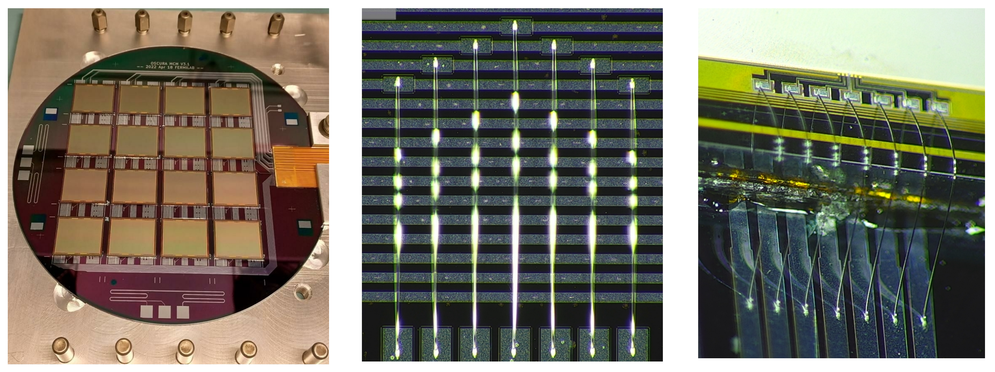

Figure 4: MCM after assembly. (Left) silicon wafer with 16 CCDs and flex cable, on the assembly tray. (Middle) aluminum wire-bonds on pads on the Silicon package; the SiO2 openings for pad connection can be seen as a thin line around the pads. (Right) wire bonds between a CCD and theSilicon wafer.

5. First tests

· First tests in vacuum vessel at 160 K
· Analog correlated double samples and multiplexer (1 digital channel)
· Images with tracks and good noise reduction with skipping
· High noise from set up

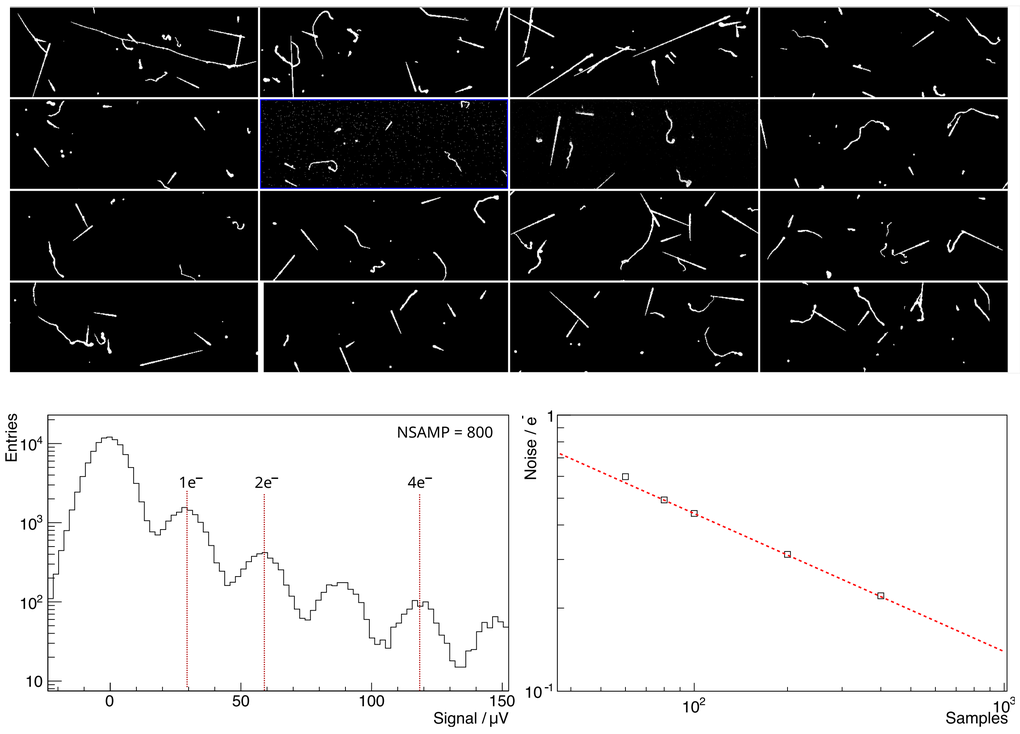

Figure 5: (Top) Image of 16 CCDs in MCM. (Bottom-left) pixel charge distribution obtained with 800 skipper samples. (Bottom-right) Noise as a function of number of samples. The analog correlated double sample recquires a minimum of 50 samples.

Summary

· OSCURA aims at 10 kg Skipper-CCD with 0.01 dru
· Silicon prototypes produced at ANL
· High-density package designed
· Tests in vacuum vessel showing tracks and good noise reduction with skipping
· Preliminary engagement with production facility to process 1500 wafers

More information and references in QR