Nuova Officina Assergi: the inNOvAtive facility for the production of large area Silicon Photodetectors

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on behalf of the NOA group

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Where is NOA?

NOA is located in L'Aquila (Italy), in the external labs of Laboratori Nazionali del Gran Sasso (LNGS).

The underground tunnels of LNGS host the biggest underground laboratory in the world, running state-of-the-art experiments about dark matter, neutrino and rare event physics.

What is NOA?

NOA is a 420 m^2 ISO-6 clean room designed for assembly and testing of large-area silicon detectors.

- currently involved in the production of SiPM arrays for the DarkSide-20k experiment

Great potential for use in future fundamental physics experiments

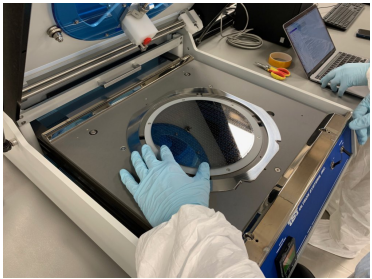
- professional tools for silicon detectors assembly
- dedicated characterization setups for photodetectors
- availability of liquid nitrogen for cryogenic device testing
- high capacity for storage
- qualified technicians for shift operations and electronics design

Assembly tools (part 1/3)

More details in *L. Consiglio et al., Front. Phys. 12:1433347*

Frame mounter

Silicon wafers up to 8" can be mounted on a handling structure with a metal ring and a thin plastic film for protection and support.



Dicer

Silicon dies can be separated by a programmable dicer featuring a circular diamond saw with 1 µm cut accuracy.

Different saws can be used to cut different thin substrates.

A jet of demineralized water is employed for saw cooling and debris removal.

Assembly tools (part 2/3)

UV exposer

UV curing for tape release up to 8" diameter plus holding frame

Die expander

Mechanical die separation of cut wafers by tape expansion and grip ring mounting for easy handling.

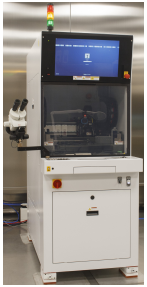
Assembly tools (part 3/3)

Die bonder

Separated dies after expansion can be bonded to their electronics boards via a pick and place system or flip-chip bonding also at high temperature. NOA's die bonder features an automated procedure of glue dispensing, wafer loading, SiPM placing and soldering paste heating.

Wire bonder

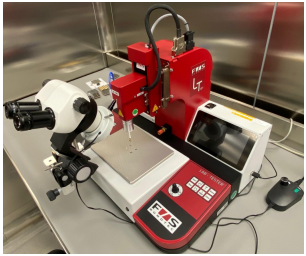
A programmable wire bonder can place wedge-wedge, ball-wedge or ribbon bondings with few µm precision.
It features an image recognition system for automatic alignment.



Other production tools (part 1/2)

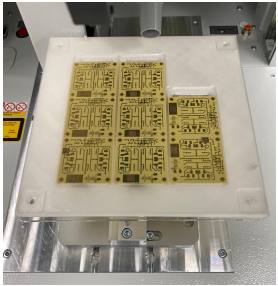
Pull tester

Manual tool to remove defective wire bondings and measure the needed force to detach one of them.



Laser engraver

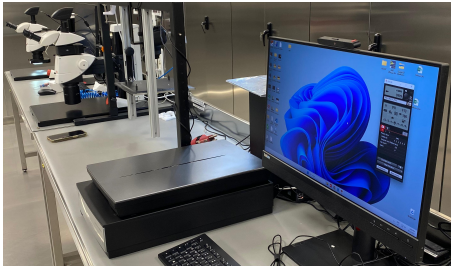
NOA's detectors are uniquely identified by QR codes engraved by a Nd:YAG pulsed laser.
The laser can engrave all patterns that can be represented as a vectorial image.
It accomodates 3D printed supports for any type of detector shape.



Other production tools (part 2/2)

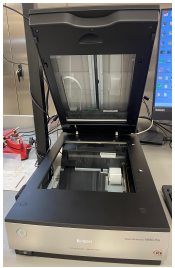
Optical inspection

Two microscopes with SiPM-level and SPAD-level magnification are available for detailed optical inspections.
A photo camera stage is also available to document the detector state with pictures.



Dust counting

The counting of pollution particles on detector surfaces will be carried out by means of a high-resolution scanner.
It could be used also for transmission scanning of radiochromic films.
The scanner will be installed in few months.



Test side of NOA

Half of NOA is dedicated to photodetector characterization
at room temperature (warm) and in liquid nitrogen (cold)

Hardware equipment:

- SiPM test on wafer with a professional machine
- custom setups for warm and cold electro-optics characterization of large-area SiPM arrays
- CMOS camera for SiPM arrays debug (recently added)
- dark count rate (DCR) measurement

Software efforts:

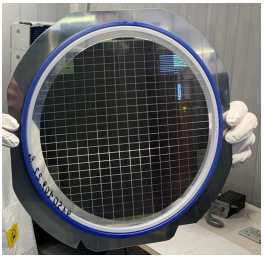
- QC tests automated by Labview
- taken data saved on the DS collaboration database
- scripts for automatic data analysis
- webpage for consulting the history and the test results of assembled devices

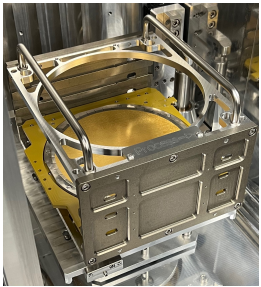
Silicon detectors test setups (part 1/4)

SiPM test

The SiPMs can be tested directly on the wafers by a professional cryoprobe.
The wafers are cooled down to 77 K in vacuum.
A warm test is also possible.

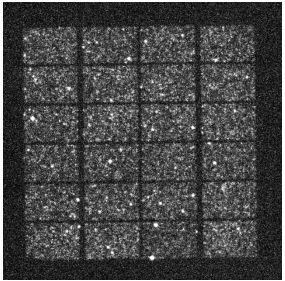
The cold test of 1450 wafers (production + engineering) for DS-20k has been successfully completed.



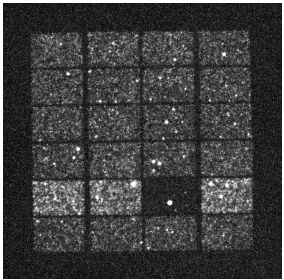


CMOS imaging

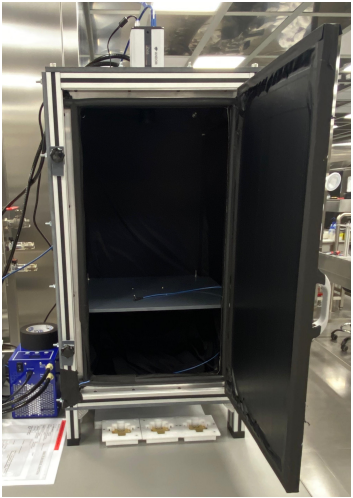
- 16-bit CMOS to measure the near infrared emission of biased SiPM arrays
- a quick scan (30 s) reveals SiPMs with critical misbehaviors
- defective SiPMs are replaced by our die bonder



GOOD



BAD



Silicon detectors test setups (part 3/4)

Tile

DarkSide-20k Tiles are composed by
24 SiPMs mounted on a single PCB

- designed for operation in liquid argon ($T = 87\,\mathrm{K}$)
- quantum efficiency $> 40\%$ at 420 nm
- readout by a single low-noise trans-impedance amplifier (TIA)

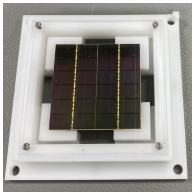
Tile test

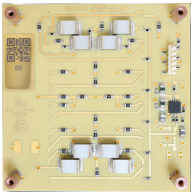
Electronics and optics qualification of the Tiles
Warm and cold characterization:

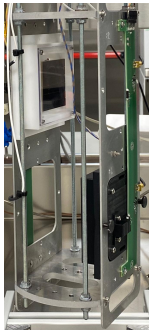
1. I-V curve
2. noise power spectrum

Cold characterization:

- laser-triggered fingerplots
- pulse count rate (PCR), dedicated setup for DCR (sample measurements)



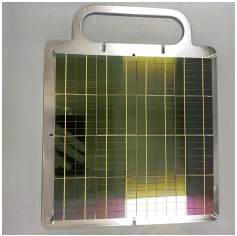


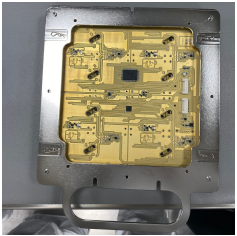


Silicon detectors test setups (part 4/4)

Photo Detection Unit (PDU)
16 Tiles mounted on a motherboard form a PDU

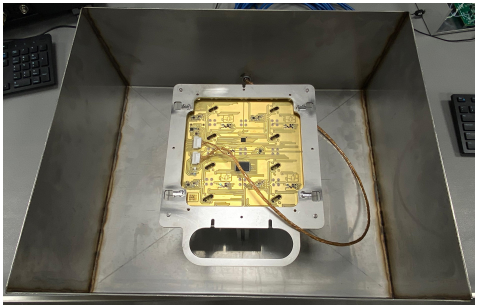
- $20 \times 20\,\mathrm{cm}^2$ SiPM-based photodetector
- 4 differential output channels (quadrants)
- fundamental tesselation unit of DS-20k optical planes ($21\,\mathrm{m}^2$ in total)





PDU test
Warm PDU qualification
in a dark box:

1. I-V curve of all the Tiles
2. power noise spectrum of all the Tiles



Cold PDU test carried out in a dedicated facility in Napoli

Clean Room 2

Dedicated clean room (CR2) with a 5.8 m roof for detector mounting

Used for the first time for mounting the DS-20k mockup

The optical planes of the TPC of DS-20k will be assembled in CR2

NOA perspectives

Flexibility to accommodate CR3 and CR2 for different types of silicon-based detectors productions

Possibility to implement a Radon abatement system (1 M€ estimated cost)

Memorandum of Understanding in agreement with LNGS Directorate
for NOA usage by different experimental collaborations

- access rules
- operating procedures
- technical aspects and plant design of the CR
- description of the packaging machines
- cost for running and maintenance

Conclusions

Summary of NOA features:

- clean room for production and integration of large-area silicon detectors
- built for DarkSide-20k (first and unique user until the end of 2026)
- available from 2027 to other research groups upon request
- suitable for high-density interconnected PCBs
  for physics experiments or industrial sensors development

Available technologies not used for DS-20k:

- the cryoprobe can be equipped with custom designed probecards
- different methods of die bonding:
  TSV, TCB, 3D IC, 2.5D IC, Flip Chip, Chip on Chip, Chip on Wafer, Chip on Substrate, etc...
- the wire-bonder has dedicated wedges
  for ball and ribbon bonding with wire range from 7.5 to 75 µm

Thank you for the attention!