

NUOVA OFFICINA ASSERGI: future perspectives beyond DarkSide-20k

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The Nuova Officina Assergi (NOA) is a functional Research and Technological Development Unit realized at LNGS and operational starting from February 2023. Flagship of INFN for the production and integration of silicon devices operating at cryogenic temperatures, NOA occupies an area of 420 m² with reduced radon concentration and is equipped with cutting-edge technology machines: a cryogenic Silicon device probe, a semi-automatic dicing system, a high-speed dual bond head flip-chip bonder and an ultrasonic wedge-wedge and ball-wedge wire bonder. The next 2 years the facility will host the DarkSide-20k activities for the packaging and assembly of more than 21 m² of cryogenic photosensors, that will be integrated in the Time Projection Chamber of the detector. In perspective NOA, could offer a valid alternative to industrial processes often costly, becoming an opportunity for all the collaborations and research centers, interested in the development of emerging technologies of interconnections for the integration of customized Silicon photomultipliers such as Trough Silicon Vias or module integration of hybrid and monolithic pixel detectors. We will discuss in details the NOA facility as a possibility for assembling photosensors for dark matter detectors.

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1. Introduction

NOA is a novel facility located at Laboratori Nazionali del Gran Sasso (LNGS), in the external Laboratories, inside the building called “Hall di Montaggio”. The NOA concept was conceived in 2016 within the framework of the DarkSide-20k experiment [1] and has been realized thanks to two Italian government fundings: “Piano Operativo Nazionale 2014-2020” (PON) and “Programma di Sviluppo RESTART, Delibera CIPE 49/16” and also through an agreement between LNGS, Abruzzo Region and Comune dell’Aquila in the field of the scientific research. NOA is an ISO-6 clean room according to the ISO 14644-1 standard and is divided into two main areas: the larger one called CR3 occupying a surface of 350 m² is devoted to the test, packaging and integration of SiPM-based detectors employed at cryogenic temperatures; the second one called CR2 with an area of 70 m² is intended to be dedicated to the handling and set-up of detector parts (like the assembly of the optical planes in the DarkSide-20k case before the final assembling in the Time Projection Chamber of the detector underground). The NOA infrastructure has been realized in stainless steel material to reduce the radon (Rn) emanation and is also compatible with the installation of a Rn abatement system that would make NOA a Rn free clean room with an expected Rn concentration in the air reduced by at least of a factor 100.



Figure 1: left: CR3 area for photodetector test and assembly; right: CR2 area for large detector part integration.

2. NOA packaging and testing area

NOA CR3 has been equipped of auxiliary plants providing utilities such as compressed air, vacuum, ultra-pure water, gas and liquid nitrogen, industrial water, refrigerated water. A portion of CR3 has been adhibited to the handling, test and packaging of Silicon devices, with the installation of commercial highly sophisticated machines (see fig.2):

- the Form Factor PAC200 [3], a highly-precise semi-automated probe station for wafers and substrates up to 200 mm in a high vacuum environment, for testing devices at cryogenic temperatures down to 77 K;
- the Advanced Dicing Technology 7122 [4], an automatic wafer dicer with 200 mm x 200 mm dicing area, for dicing Si wafer on other thin materials and substrates with 1-micron accuracy;
- the AMICRA NOVA PLUS flip chip bonder [5], a modular machine concept with precision die attach method for micro assembly applications;
- the HESSE BJ855 [6], a high speed fully automatic fine wedge-wedge and ball wedge wire bonder;
- the Ultron manual packaging system for tape release, UV-curing, die expansion [7].

The remaining area is devoted to the assembly and integration of the photosensors after testing them with the related electronics both at room and cryogenic temperatures. To this purpose each workstation has been equipped with electricity (220V, 50Hz) from normal and UPS power supply, compressed air, low pressure gas nitrogen and vacuum. Moreover two high resolution microscopes have been installed for the optical inspection and quality control during the sample production.



Figure 2: NOA packaging area in CR3: top left: cryo probe station; top right: flip chip bonder; bottom left: manual tools for packaging; bottom middle: Silicon dicer; bottom right: wire bonder.

3. Photo-detector production in NOA

The DarkSide-20k collaboration is the first user to adoperate the NOA infrastructure in order to realize the production of 528 Photo Detection Units (PDUs) for a total area of 21 m² of large arrays of cryogenic NUV-HD Cryo Silicon Photo Multipliers (SiPM) [2] developed by Fondazione Bruno Kessler (FBK Trento IT, <https://www.fbk.eu/en/>). Each PDU is made of 16 sub-modules called “tiles”, integrated on the “Motherboard” printed circuit board (PCB) and grouped into 4 electronic readout channels. To achieve this goal the characterization of 1400 Silicon wafers produced by LFoundry (<http://www.lfoundry.com/>) is in progress to be followed by the packaging of the Silicon dies according a well defined process flow:

- **wafer cryo probing:** all the SiPMs of each wafer 200 mm diameter and 550 μm thick, is probed individually inside a vacuum chamber at 77 K to sort devices based on their quenching resistance, breakdown voltage and leakage current discarding the ones that do not meet well pre-defined acceptance criteria;
- **dicing:** each tested wafer is mounted on a tape film inside a grip ring, then it is diced in 268 dies sized 11.8 mm x 7.8 mm each. The film is UV cured and expanded in order to move the SiPMs away from each other and facilitate the next step of the pick-up for die bonding;
- **flip chip bonding:** the wafer is placed into a custom holding frame and positioned inside the machine. The SiPMs that have been validated by the cryo probe are soldered one by one onto the top side of the tile PCBs (provided and populated with electronic components by external companies) on which an Indium soldering paste has previously been dispensed. The machine has been customized to perform the die bonding of 16 PCB tiles at a time by means of a thermal compression process thus creating a low-resistance electrical contact between the SiPM backside (cathode) and the tile PCB;
- **wire bonding:** this process builds a low-resistance electrical contact between the anode of the SiPM and the tile PCB. The contact is made by means of an Aluminum conductive wire through a wedge wedge bonding, that joins the anode pad of the SiPM with the contact pad of the tile PCB;
- **tile testing:** after an optical inspection, each tile is tested on a mechanical set up inside a small dewar first at room temperature and then immersed in liquid nitrogen in order to perform a full characterization of the devices to be qualified in terms of electrical and functional performances;
- **PDU assembly:** the validated tiles will be integrated manually on the PCB Motherboard (also provided and assembled by external companies) in order to build a PDU that after an electrical test at room temperature is shipped to the Naples test facility for the full device cryogenic final validation.

All the operations in the clean room are developed according well defined clean room operating protocols for handling and storing all the devices and parts that will enter the final detector to minimize as much as possible the surface contamination and the radon exposure.

4. Future perspectives

The NOA facility at LNGS is a clean environment devoted to the production and integration of arrays of SiPMs in a dust controlled area with low radon emanation. The facility has become operational since February 2023 and currently the DarkSide-20k collaboration is running the operations to set up the massive production of 528 PDUs that is foreseen to start in the beginning of 2024. The machines have been partially customized and configured according to the DarkSide-20k requirements but since they are commercial machines, there is enough flexibility to adapt them basing on different designs. The Form Factor cryo probe station, can be configured with different probe-card technologies currently available on the market that can be integrated in the machine set up. The flip chip bonder NOVA PLUS is one of the most advanced die bonding systems: a high precision machine for semiconductor packaging with a high place accuracy, able to bond with temperatures exceeding 350°C applying a controlled force. This Thermo Compression Bonding feature is requested by several applications like Through Silicon Vias, 3D/2.5D Interconnections, Flip Chip with different substrates and many more. The HESSE Wire Bonder is the latest generation of fully automated fine wire bonders equipped with bond tools for wedge wedge (wire, ribbon) and ball bonding. An interesting perspective for NOA that is under evaluation at LNGS through a feasibility study, is the implementation of a Radon abatement plant (estimated cost around 1 Meuro). This upgrade would make the infrastructure unique for the packaging, test and assembly of photodetectors in a Rn free environment. A Memorandum of Understanding of the infrastructure is being elaborated, collecting the access rules, the operating procedures, the technical aspects, plant design of the clean room, the detailed description of the packaging machines, the cost for running and maintenance. NOA is already receiving expression of interests from other collaborations and research groups that are going to be accommodated during the DarkSide-20k operations and in the near future the plan is to make the NOA clean room and its equipment available for all the users interested in such kind of technologies.

References

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