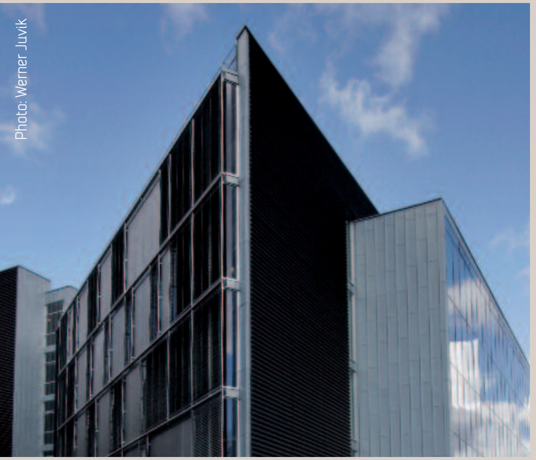
The SINTEF Group is the largest independent research organisation in Scandinavia.
We find intelligent and profitable solutions for our clients based on research and development in technology, medicine, the natural and social sciences.

SINTEF Media, 2008

Photo: Werner Juvik



The new 1200 m^2 semiconductor research and processing facility built in collaboration between SINTEF and the University of Oslo. The facility is equipped for processing 100 mm and 150 mm silicon wafers.

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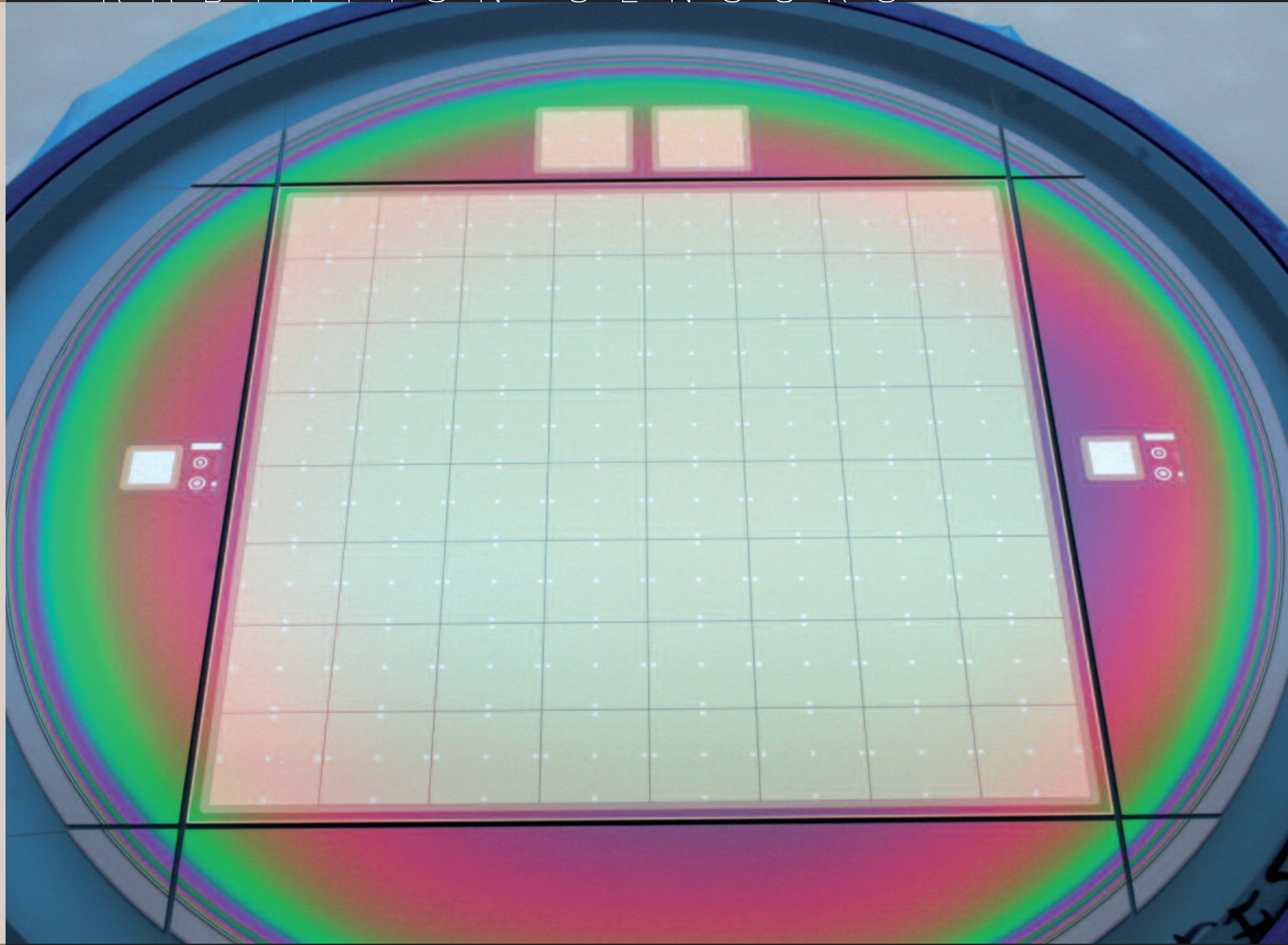
SINTEF Technology for a better society

silicon

RADIATION SENSORS



SINTEF

Technology meeting your applications

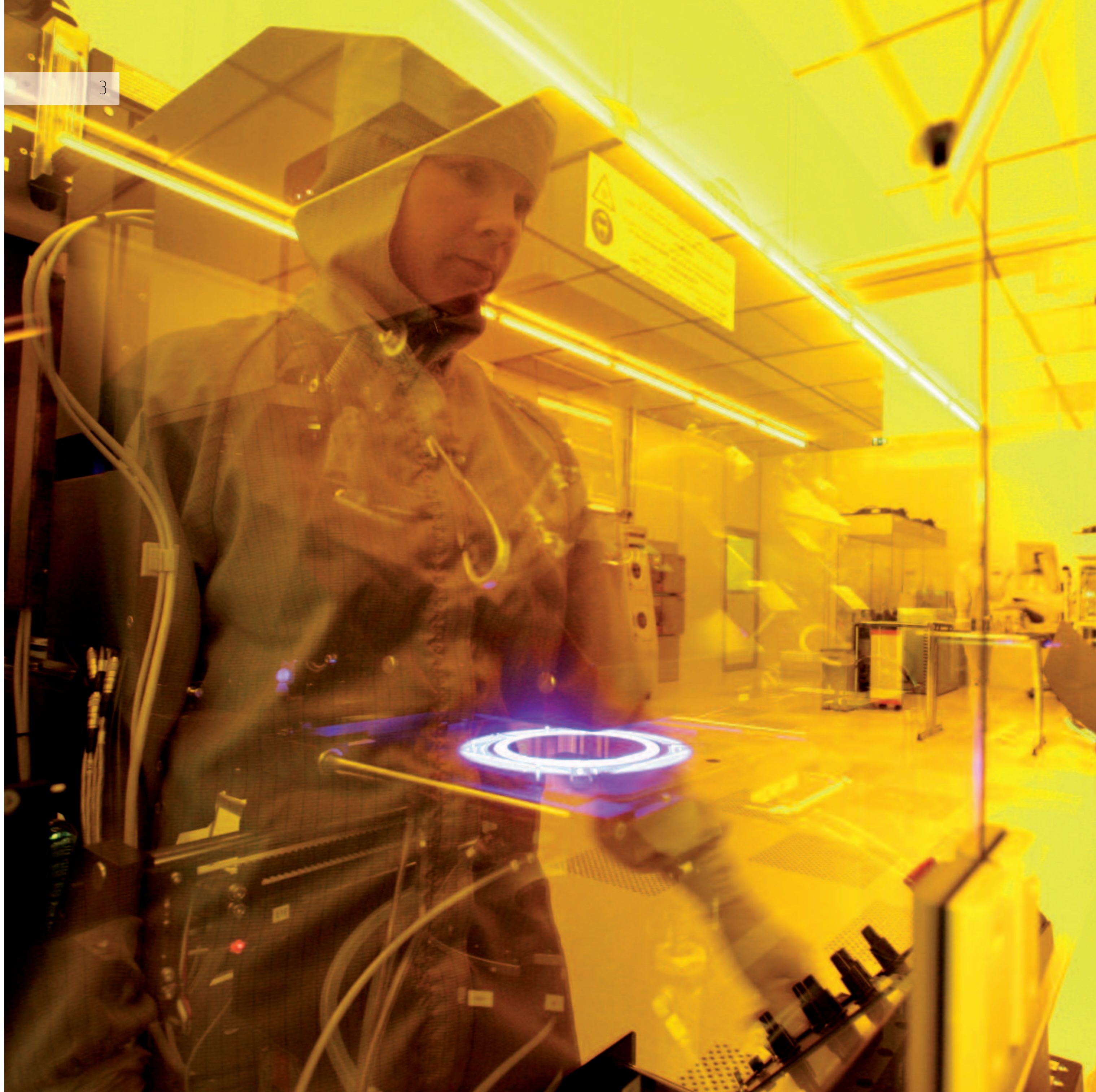
SINTEF develops and manufactures silicon radiation sensors adapted to customer specifications and requirements. Our services range from prototype development and device optimization to foundry services and customer specific fabrication. Through our in-house design and processing facilities, we offer flexibility at every level, from initial design through prototyping to final sensor production.

Meeting your needs • Sensor design is performed by SINTEF according to customer specifications and need. Customers may also provide the complete and final design and even the masks. We pride ourselves for flexibility, and are happy to discuss design and manufacturing details to assist the customer to tailor a product that meets the requirements in full. The final product may be the sensor chip only, or a complete solution with application-specific front-end electronics (FE-ASICs).

Application areas and customers • Silicon radiation sensors are used for detection of optical and X-ray photons, high-energy particles and ions. It is possible to perform photon counting, and high resolution position or energy measurements. Typical applications are X-ray imaging and material analysis, particle tracking and ion identification. SINTEF has manufactured radiation sensors for a wide range of customers. These include international research organisations such as CERN, DESY, Brookhaven National Lab, Fermilab, Argonne National Lab, ESRF and INFN, as well as universities in Europe and the US. We also produce sensors for European and US companies for X-ray waste management and material analysis, medical applications and various optical applications including sun sensors for space navigation.

Our silicon technology • The SINTEF silicon radiation sensor technology has evolved through a series of challenging projects and development programmes since the early 1980ties. The basic processes and long experience enables us to design and deliver sensors that meet the most demanding customer requirements. One corner stone is an ultra clean processing facility in combination with a proprietary getter process that achieves unsurpassed leakage current levels. In combination with appropriate design solutions, this gives sensors with very low noise levels.

Focused activities • Silicon radiation sensors, Microfluidics, Microoptics, Sensors with functionalized materials, and 3D-integration of sensors.



Microstrip sensors

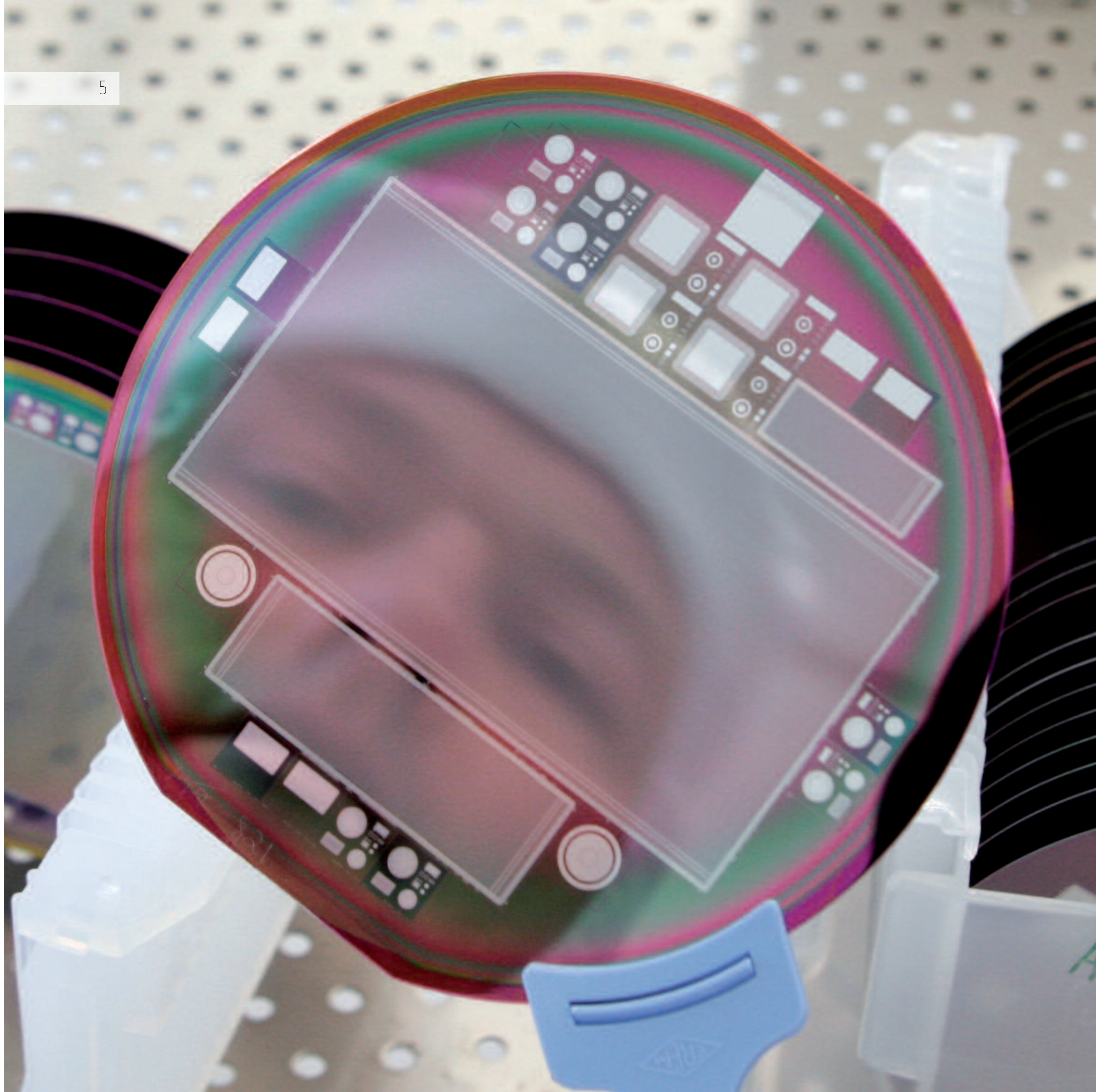
Microstrip sensors are used in applications where good position resolution and fast read-out are important. A typical example is vertex detection in high energy physics collider experiments at international research laboratories such as CERN and Fermilab. Industrial applications include X-ray material analysis, and medical imaging.

Single-sided strip sensors • Single-sided sensors have p+ implants formed as long strips on the front side. Their back side has a highly doped uniform n+ implant covered with metal.

Double-sided strip sensors • Double-sided sensors have a front side that is similar to a single-sided sensor. On the back side there is a pattern of n+ implants formed as long strips. These will usually be orthogonal to the strips on the front side in order to obtain two-dimensional resolution. The backside n+ strips may easily be short circuited due to the accumulation layer formed by the positive oxide charge. This is solved by isolating the strips by using either p- spray implants, p+ - stop rings, or metal field plates biased to form an inversion layer between the strips.

Microstrip sensors can be made DC coupled or AC coupled. On DC coupled sensors each strip just has a pad for direct bonding to an amplifier channel. The more advanced AC coupled sensors have integrated coupling capacitors and resistors on chip for signal read out and biasing. This facilitates testing, as the sensor I-V characteristics can be measured by making only two contacts: To the p+ bias line on the front side and to the n+ contact on the back side.

The position resolution of a strip sensor depends on the centre-to-centre distance between the strips, called the pitch. By using charge division read-out, the position resolution of the sensor can be pitch/√12.



Pixel sensors

Pixel sensors have the advantage of a very fast read-out, without the position ambiguity of double-sided strip sensors that are hit by several particles simultaneously.

Pixel sensors with good position resolution require a very large number of electronics channels per unit area. For making contact between the pixels and the electronics there are two possibilities. One option is to mount the sensor and the electronics chip face-to-face using flip-chip techniques. The other alternative is to use double layer metal to connect the pixels to bond-pads at the sensor edge.

The position resolution of flip-chip mounted sensors is limited by the area of each electronics channel.

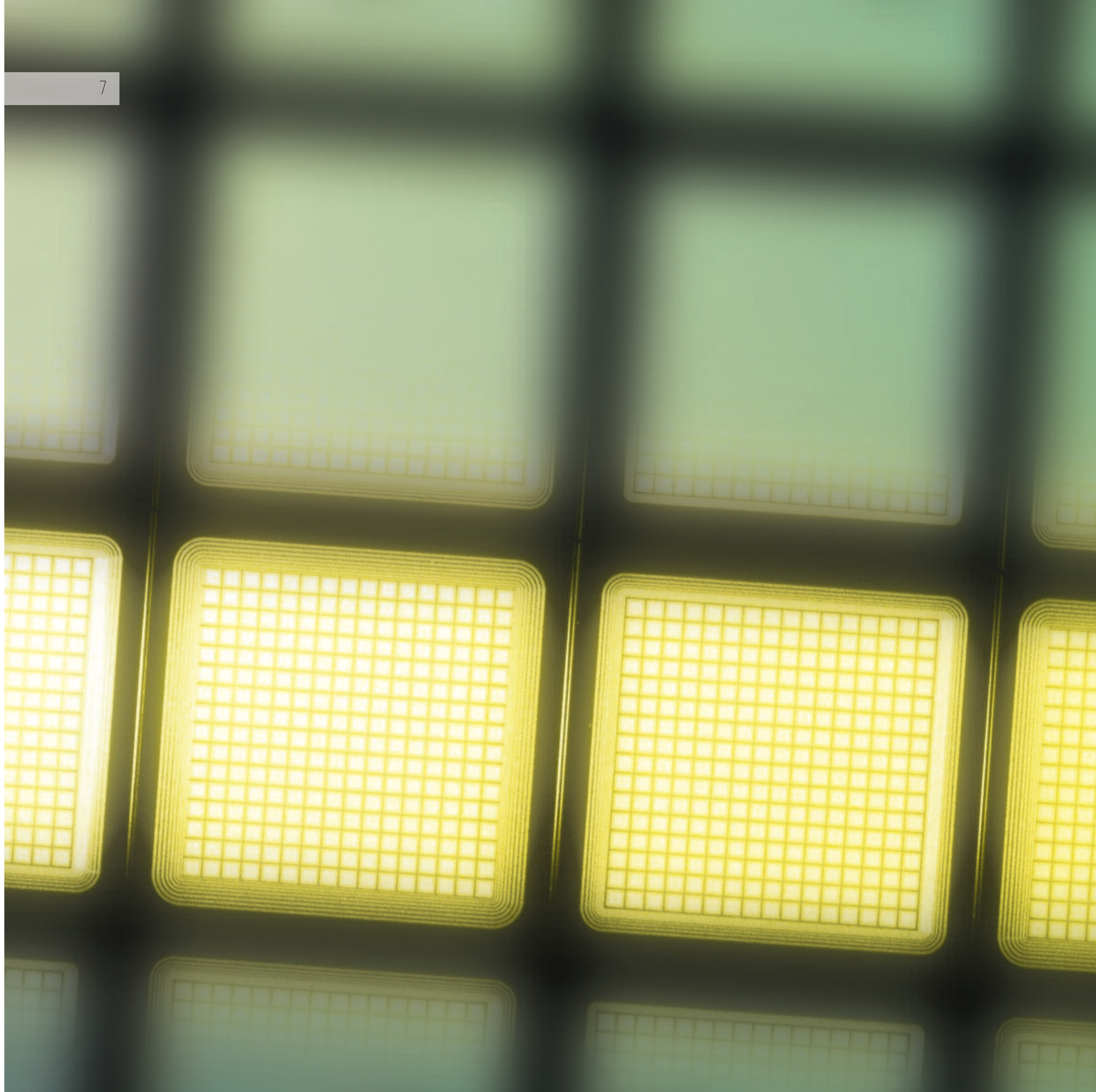
By designing the pixels and the electronics in a non-quadratic shape, a better position resolution can be obtained in one of the directions. The advantage of pixel sensors compared to double-sided strip sensors or drift chambers is that they provide two-dimensional position resolution with single-sided processing.

With double-sided processing and a thin entrance window on the back side, low-energy particles and soft X-rays can be detected.

By making an optical window on the back side with an optimized AR coating, the sensor can be tuned for detection of light at specific wavelengths. Possible applications are readout of segmented scintillators, laser tracking and optical imaging.

3D-sensors • In 2008 SINTEF as the second laboratory in the world after Stanford/SLAC demonstrated full 3 dimensional (3D) sensors with active edge. In the 3D-technology vertical electrodes penetrates the entire substrate, and the devices offer advantages such as ultra-fast time response, edgeless capability and unique radiation hardness. This has drawn high interest for future particle tracking, medical imaging and possibly security applications. In the full 3D-design the electrodes and active edge trenches are filled with polysilicon, making the devices sensitive up to the physical edge.

Edge illuminated sensors • In this configuration the incident photons illuminate the sensor edge, either at normal incidence or at a small angle. This offers the advantage of a very long absorption length without needing to process very thick silicon material, and without increasing carrier transit time. In this way edge illuminated structures make efficient X-ray sensors even at energies > 150 keV, and competes favourably with scintillator detectors. Applications include medical imaging and line scanners for material analysis and waste management.



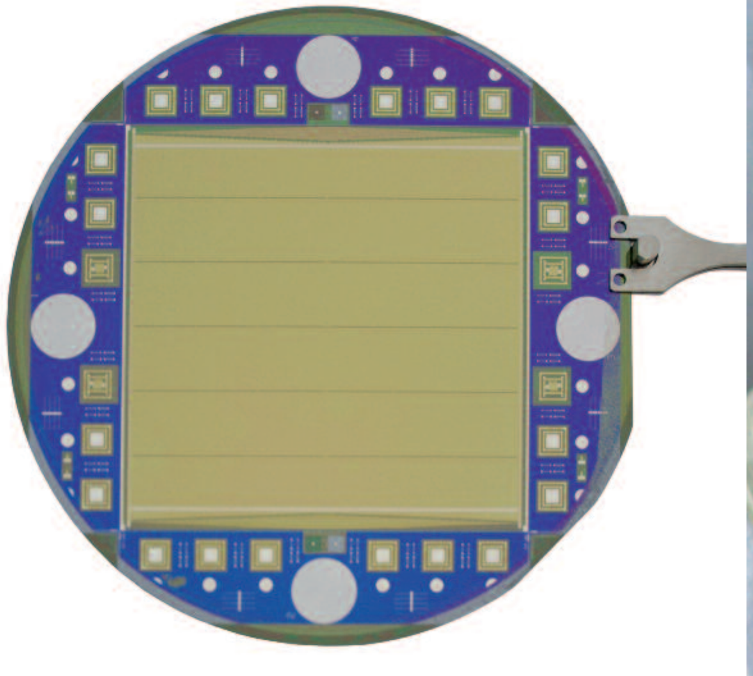
Drift chambers

Silicon drift chambers offer low read-out capacitance at the price of a longer read-out time compared to other sensors. They can be designed for two dimensional position sensing with the advantage of using far less electronic channels than strip sensors. Alternatively they can be made as diodes with extremely low capacitance

The silicon drift chamber is the solid-state equivalent of the gas drift chamber. It can be used as a vertex sensor in collider experiments with low event rate, or in the diode configuration as a low noise sensor for scintillator readout or direct detection of low energy X-ray photons.

The sensor has a pattern of cathodes (p+ implants) on both sides of the silicon wafer that controls the lateral drift field. The signals are read out at n+ anodes. By using several segmented anodes, two-dimensional position resolution can be obtained. One dimension is calculated from the drift time, while the other is given by the anode position.

In the diode configuration the cathode on one side acts as radiation entrance window. The other side holds concentric cathode rings with a small central anode. The result is a sensor with extremely low capacitance for applications requiring very low noise levels. If the entrance window is made with a shallow dead layer, this makes a powerful tool for material analysis using soft X-rays.



Thin and thick sensors

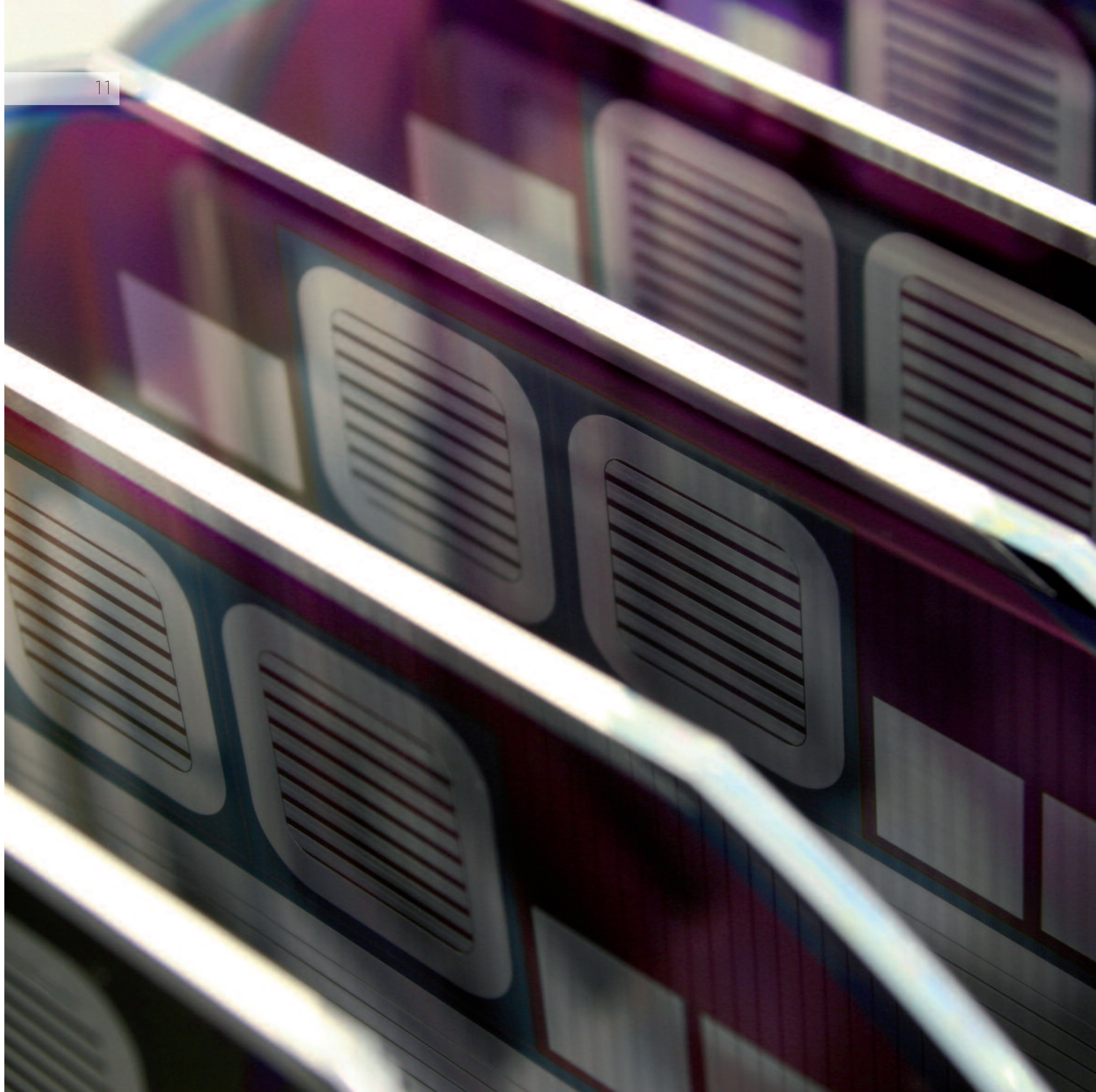
A combination of thin and thick sensors can be used for particle identification by spectroscopy. Thin sensors also have the advantage of being fast.

Silicon wafers with thickness in the range of 135 mm to 2 mm can be processed. By using a special silicon etching technique, we are able to fabricate small sensors with a thickness in the active area as thin as 10 mm. These thin sensors have been used for spectroscopy of heavy ions, and they have also been tested as beam monitors.

The standard silicon thickness for processing is between 300 µm and 500 µm. For significantly thinner and thicker wafers, special precautions are taken during processing. In 2008 SINTEF successfully demonstrated processing of double sided strip detectors on 2 mm thick, 150 mm diameter wafers, probably as the first lab in the world.

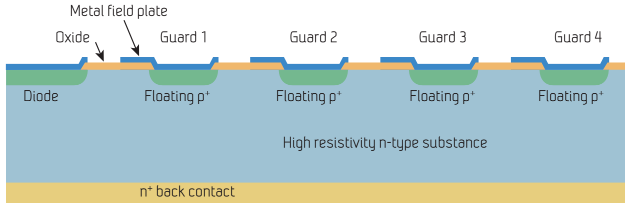
Thin wafers are brittle and must therefore be handled very carefully. Thick wafers are difficult due to their weight, so special carriers with sufficiently large slot sizes must be used. One must also be careful with automatic handling equipment adjusted to handle wafers of the standard thickness. Thus non-standard procedures and manual handling must be employed and the processing price increases.

Sensors with a thin membrane created by silicon wet etching from the back side can only be made with patterning on the non-etched side. Due to the topography the back side cannot be uniformly coated with photo resist, which is needed for photo-lithography.



Our technology options ...

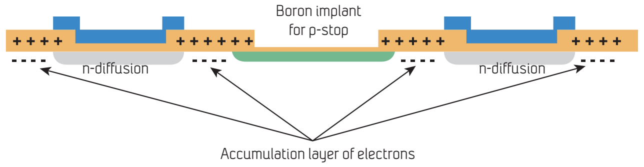
Guard structures



The purpose of guard ring structures is threefold:

- Provide a sink for the current generated outside the active area.
- Prevent avalanche breakdown by distributing the potential drop over a longer distance.
- Improve the long-term stability by controlling the potential distribution at the surface of the sensor.

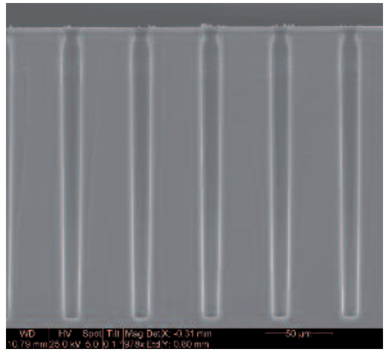
N-side isolation



In n-type material, the positive oxide charge induces a surface electron accumulation layer that may short circuit the n-type implants. Thus an isolation structure is required in the form of:

- P-stop: A defined pattern between the n-strips implanted with boron
- P-spray: The complete n-side surface implanted with a low boron dose

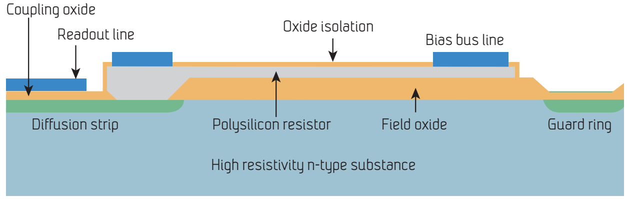
3-Dimensional structuring



Based on the SINTEF MEMS technology the sensor structures can be structured in 3 – dimensions. This includes a long established technology for very thin sensors made by anisotropic etching which offers active areas of ≥1 cm2 with 10 µm thickness, and typically ± 1 µm thickness uniformity.

Later developments are based on state-of-art Deep Reactive Ion Etching (DRIE) tools, which offer the possibility of realizing narrow holes (< 15 µm) and trenches with high aspect ratios (> 20). In 2008 SINTEF realized full 3D-sensors with active edge based on this technology, refer page 6. These are structures with vertical n-and p-doped polysilicon filled electrodes penetrating the entire substrate. A similar configuration is used for sensors with both anode and cathode backside contacts, and this may be the basis for future vertical integration of sensors and readout electronics. A more simple, but interesting application is fabrication of optical sensors with through-hole apertures.

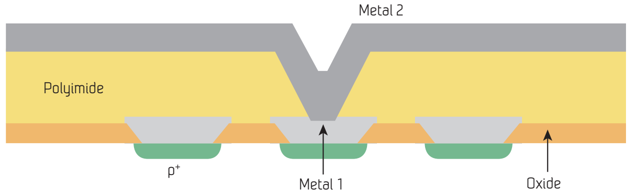
Biasing methods



Microstrip sensors can be biased with integrated polysilicon resistors or with FOXFET structures. High resistance bias resistors for low noise read-out are made from LPCVD polysilicon implanted with boron ions. The resistance can be customized to a fixed value in the 0.1 to 50 MΩ range by adaption of implantation doses and resistor lengths. This technology has a superior radiation hardness because the resistors are almost unaffected by radiation damage.

FOXFET (Field OXide Field Effect Transistor) biasing is an alternative which offers reduced costs and high dynamic resistance values. The performance of FOXFET biased sensors degrades with increasing radiation damage.

Double metal layers



By using a 5 µm thick polyimide layer as a dielectric, sensors are made with a second aluminium layer. This layer can be used to route lines from pixels to bondpads at the edge of the sensor as an alternative to flip-chip bonding. It is also used for double-sided sensors with orthogonal strips, where the bond pads to the electronics should lie along the same edge for both sensor sides.

Passivation

As an inherent part of the silicon process a thermally grown oxide passivates the silicon surface. Additional passivation in the form of a deposited two layer stack of dioxide and silicon nitride is normally applied. The passivation wil cover the aluminium metallization, and only areas needed for electrical contacts to the sensor will be opened. In case of optical sensors also the photosensitive areas are opened.

Thin dead-layers

Passivation layers, aluminium layers and heavily doped regions will absorb radiation without giving any electrical signal. It is essential that these dead-layers are minimized in order to detect radiation with a short range in silicon, such as low-energy electrons and protons or photons with wavelengths shorter than ~ 500 nm. SINTEF has made sensors with dead layers down to 0.06 – 0.15µm. For optical applications the oxide thickness over the active area will be adapted to provide maximum transmission within the specified spectral range.

Our working tools ...

Research and development at the Department of Microsystems and Nanotechnology (SINTEF MiNaLab) is carried out by a staff of highly qualified research scientists. Production is assigned to an experienced, permanent laboratory staff of engineers and technicians. A number of PhD and MSc students are associated with the department through collaboration projects with different universities.

Processing facilities • The SINTEF MiNaLab fabrication facility contains a full ultra clean processing line for 100 mm and 150 mm wafers. The line includes equipment for automatic photolithography, deposition and diffusion of dopants, thermal growth of silicon dioxide, polysilicon and silicon nitride LPCVD, silicon dioxide and silicon nitride PECVD, Al, NiCr and Au sputtering, wet silicon etching, and state of the art tools for conventional and deep reactive etching (DRIE). The facility is located in a new lab opened in 2004 with 800 m2 of clean rooms

Design • The layout of masks is done at SINTEF using the program L-Edit Pro from Tanner EDA and the design files are sent electronically to the mask vendor. We also accept design files from our customers provided they have been designed according to SINTEF design rules.

Testing • We have both fully automated and manual probe stations for electrical characterisation of the sensors. The measurements are performed by Keithley and Agilent instruments in set-ups controlled by LabView™ programs.

Simulations • are important for development of processes and designs that yield the desired results. Here we use the simulation tools provided by Silvaco Inc. These tools include ATHENA™ for one- or two-dimensional process simulation. The electronic properties of the devices can be simulated using ATLAS™.

Silicon Micromachining • State of the art dry etching, deposition and wafer bonding tools facilitate non-planar processing of radiation sensors.

ASIC design and sensor packaging • SINTEF has successfully designed application-specific integrated circuits for front-end electronics for several customers. We also have extensive experience in techniques for packaging and cooling of silicon devices.