A 256-TES array for the detection of CMB B-mode polarisation

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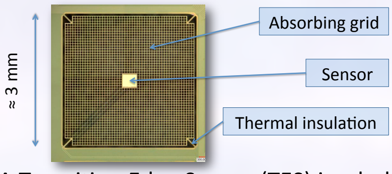
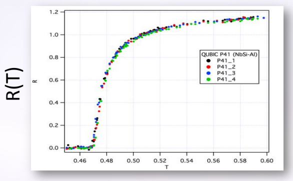
Context

The **Cosmic Microwave Background** (CMB), very first light emitted by the Universe, is a fundamental source of information for modern cosmology. Partly polarised, this radiation should display imprints left by gravitational waves during the early Universe : **B-modes**. As it would **constrain inflation models**, millimetre-wave detection of B-modes is therefore one of the most challenging issue of present cosmology. In order to detect this very faint signal, next generation of CMB instruments needs **large detector arrays** to ensure **high sensitivity** in addition to a good control of systematic effects. We present here the manufacturing process and first cryogenic results of a ¼ of the QUBIC instrument's focal plane which targets B-modes.

The TES, a superconducting bolometer

A bolometer is a **thermal detector**. It consists first of a grid that **absorbs** incoming waves. This absorption causes an increase of temperature measured by a **sensor** whose **resistance** is **temperature-dependant**. The information on the incoming wave is contained in the resistance fluctuations of the sensor. The bolometer is thermally insulated from its environment by **legs**.

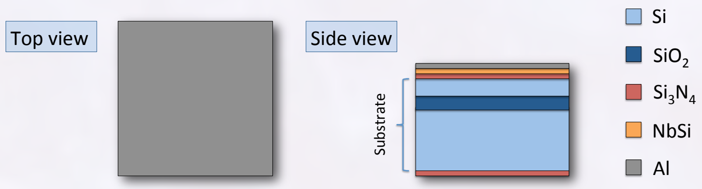




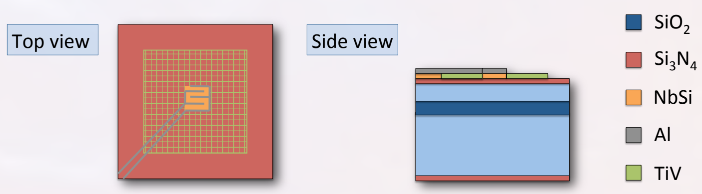
A Transition Edge Sensor (TES) is a bolometer with a **superconducting thermometer**. It is polarised so as to operate on its transition, where **small temperature fluctuations** lead to **large resistance changes**.

Manufacturing of a 256-TES array

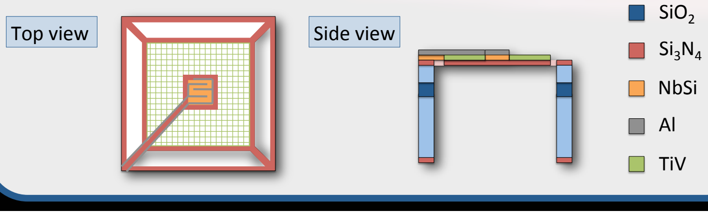
- TES arrays are crafted following several **microfabrication** steps performed in a **clean room**. First, the **Si_3N_4 membrane**, the **NbSi thermometers** and the **Al wires** are fully evaporated in layers on top of a **SOI** (Silicon on Insulator) substrate.



- The top two layers (Al and NbSi) are then respectively etched to the shape of wires and thermometers. After that step, **room temperature tests** can be performed to **control the routing**. The **TiV absorbing grid** is then deposited on the top by lift-off.



- The back layers are removed to **release the membrane**, then the legs are excavated from the Si_3N_4. The bolometers are at the end of the process completely **in suspension**.



NbSi thermometers with tunable T_c

A specificity of our design is that our sensors are made of **NbSi**, an amorphous material that can exhibit either an insulating, a metallic or a **superconducting** behaviour depending mostly on the **percentage of Nb**. The critical temperature can be inferred from that percentage then reduced to fit our needs by **annealing** the sample.

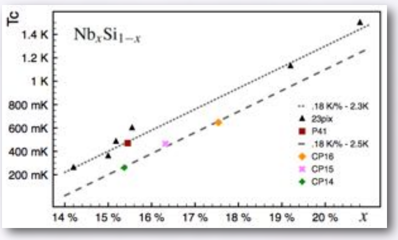
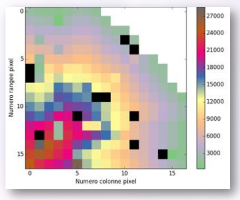


Figure : Critical temperature of NbSi sensors as a function of Nb percentage before annealing. Two different methods are compared : co-evaporation (dotted line) and co-sputtering (dashed line) technique.

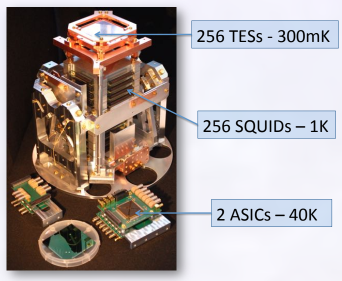
Control tests



In order to control the yield of an array, each of the 256 TESs is electrically and individually **tested at room temperature** before cryogenic integration. This operation doesn't provide any information on the bolometers' performance at cryogenic temperature but is essential to make sure that at least 90% of the TESs is **correctly connected** at the end of the production line.

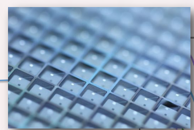
Read-out chain

For cryogenic tests, the TESs are **voltage biased** and cooled down to ~ 300 mK. They are then coupled to a **1:128 time domain multiplexing electronics** based on SQUIDs with an additional SiGe integrated circuit which provides a second multiplexing stage.



First results at cryogenic temperature

A 256-TES array has a critical temperature (T_c) around **420mK** and is regulated in a dilution fridge at a temperature below T_c. Being **voltage-biased**, the TESs work at a stable and controlled temperature due to an **electrothermal feedback** : any variation of temperature of thermal origin will induce an opposite electrical temperature regulation.



Close up on an array of TESs

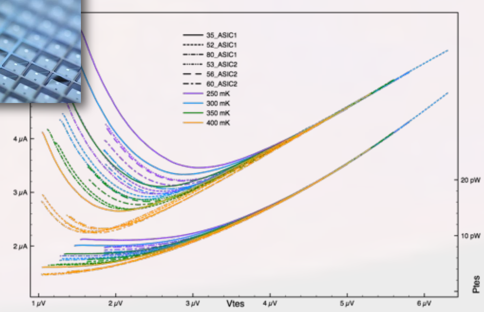


Figure : I-V (upper left) and P-V (lower right) curves of 6 selected TESs regulated at different $T_{bath}<T_c$.

When regulated at $T_{bath}<T_c$, a TES can be forced into its normal state by maintaining **high bias voltage** (right part of the curves). While decreasing the voltage, the TES slowly transits to its superconducting state and the **electrothermal feedback starts** (minimum of the I-V curves). Thus the TES works at **constant power** (plateau on the P-V curves). The figure also shows **good homogeneity** between the pixels.