

## **Market consultation**

**for: a cryogenic sample prober**

### **Contracting authority:**

The Netherlands Organisation for Applied Scientific Research TNO

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## 1 Introduction

The document describes the organisation TNO, its content and objective of the market consultation, the schedule, preconditional and procedural matters.

TNO, department Quantum Technology intends to purchase a 300K down to ~6K cryogenic sample prober (hereafter referred to as CSP). TNO would like to gain more information from the market by conducting this market consultation. The gained information might be used as input for the formal Tender process. Therefore, any party which is able to deliver such system for the purposes described in section [3] is invited to contact TNO to present the costs and (technical) possibilities of their CPS.

After this market consultation TNO will decide which Tender procedure is the most appropriate choice to buy a cryogenic sample prober.

### 1.1. TNO

TNO, the Netherlands Organisation for applied scientific research, was founded by law in 1932 to enable business and government to apply knowledge. As an organisation regulated by public law, we are independent: not part of any government, university or company.

TNO connects people and knowledge to create innovations that boost the competitive strength of industry and the well-being of society in a sustainable way. This is our mission and it is what drives us, the over 3,400 professionals at TNO, in our work every day. We work in collaboration with partners and focus on nine domains.

### 1.2 Organisational structure

TNO's high level of ambition demands an appropriate organizational structure and corporate culture. Staff must be given every support as they pursue innovation and productive cooperation. The current organizational unit structure is shown below:



All units are concerned with issues which are high on the national and European innovation agenda. The themes form the focus of the organization's nine units, each of which is responsible for acquiring and performing contract research relevant to its specific theme and innovation areas.

If you would like further information about a domain or a specific subject, please take a look at: [www.tno.nl/en](http://www.tno.nl/en).

### 1.3 Procurement

On behalf of TNO, the Procurement department supervises all procurement, purchasing and tendering procedures and works closely together with the Quantum Technology department in this market constellation. As part of the Finance, Procurement & Legal (FPL) division, the Procurement Department is also responsible for organizing and implementing all procurement processes in keeping with the corporate objectives of the organisation.

### 1.4 NanoLabNL

NanoLabNL is the Dutch national facility for nanotechnology research. Its mission is to provide a full-service and Open-Access infrastructure for R&D in nanotechnology. It has an open character and it hosts many public-private partnerships. NanoLabNL is coordinated as one infrastructure while its facilities are distributed over five cities or 'hubs': Groningen, Enschede, Amsterdam, Delft and Eindhoven. NanoLabNL is part of the national programme on quantum technology. In that

capacity NanoLabNL is dedicated to keeping its basic infrastructure ‘state-of-the-art’ to enable breakthrough-developments in the fabrication of quantum devices. In addition more specific focus is placed on high TRL infrastructure to serve the quantum agenda.

As such NanoLabNL supports scientists in their research and supports companies in improving or renewing their products/production process and/or developing new products. Finally, it aims to contribute to strengthening the Netherlands as a knowledge economy.



The hubs cooperate and share information on all possible activities, such as procurement. As a result a procurement working group has been established, within this working group, documentation, best practices, and investments plans are discussed and shared.

This Tender procedure, on behalf of TNO, contributes to the achievement of this ambitious mission.

### 1.5 Purpose of the market consultation

Before proceeding with the preparation of a possible Tender, TNO wants to consult the market on how this Tender can best be structured (broadly speaking). Within the scope of the market consultation advice is sought to gain insight into the potential market for the delivery of a cryogenic sample prober for TNO. The market consultation is open to all players in the market.

With this market consultation, TNO wishes to gain insight into what is technically feasible on the basis of the functional & technical specifications as specified in chapter 4. In this way, we want to give parties the opportunity not only to get involved at an early stage but also to think along with us about what the best solution might be for TNO. After all, the insights obtained can be taken into consideration in the final formulation of the specifications for the (possible) future Tender and allows participants to contribute to the success of the Tender.

The purpose of the market consultation is covering the following aspects:

- To gain more insights in the pricing models of the different cryogenic sample probers. The price information given will be treated confidential and will not be shared outside TNO;
- To gain more insights in discriminating factors for different configurations of cryogenic sample probers;
- To gain more insight into the current possibilities and the choice on the market; to get a clear understanding of the visions, ideas and suggestions of market participants;
- To gauge market interest for this Tender;
- To decide which procurement strategy is best suited to our functional requirements in the current market.

TNO wishes to be advised about how the existing situation (see section 3.1) can enable to the best product to be requested.

Important considerations, where there has to be a certain attention to:

- It is particularly important to us to have a prober that can maintain continuous good electrical contact, such as applying a voltage bias, while changing the temperature between 300K and base (~6K). (Section 3.1 and 3.2)
- It is important that the exposure of samples to light is controlled once the probe has made contact with the sample. For example, cooling with good electrical contact in the dark is important.
- We aim to measure multi-terminal devices and therefore we highly value the possibility to contact many pads simultaneously (e.g., 14 or more in a linear array on up to one of four sides of a device). This could be done using, for example, probe card or a multi contact wedge probe head. (Section 3.1, figure 2)
- The cryogenic sample prober should not consume liquid helium; in other words it should be a “cryogen-free” or “dry” system. (Section 3.1). This is because TNO wants avoid dependency on the supply of liquid helium which is a significant cost risk for the future.
- Controlled exposure to narrow bandwidth optical excitation, electrical access to the sample backside, application of a

magnetic field, and RF input/output are also highly desired

The results of the market consultation may be processed in the Tender documents, without being traceable of participants of this market consultation.

#### 1.6 Schedule

No dialogue sessions are planned during this market consultation. However, if the input provided leads to additional questions at TNO, TNO will ask for a written and/or oral explanation.

The schedule of the market consultation is shown in the table below.

| Deliverable / activity                                                                                                                   | Responsible    | Date                              |
|------------------------------------------------------------------------------------------------------------------------------------------|----------------|-----------------------------------|
| Market Consultation document published by TNO                                                                                            | TNO            | 28-07-2023                        |
| Deadline for submitting your questions on the Market Consultation document                                                               | Subscriber     | 18-08-2023                        |
| Deadline for TNO to reply to the questions (anonymised) and publish any additional information or revision of this document on TenderNed | TNO            | 29-08-2023                        |
| Deadline for submitting your input                                                                                                       | Subscriber     | 11-09-2023                        |
| Possibility for TNO to ask clarification to each party individually when necessary (information will be included in the summary)         | Subscriber/TNO | Between 12-09-2023 and 22-09-2023 |
| TNO summary of market consultation results on TenderNed                                                                                  | TNO            | After 22-09-2023                  |

*Dates are indicative. TNO reserves the right to amend the schedule but will of course observe all legislative requirements. Tenderers will be informed about any amendment to the schedule via TenderNed.*

## 2 Basic principles and preconditions

The basic principles and preconditions mentioned below apply to this market consultation:

- TNO observes the principles on non-discrimination and transparency when carrying out this market consultation;
- This document is solely intended for market consultation purposes and thus is not part of the possible Tender procedure. In short, just a consultation round;
- This market consultation does not serve to make a pre-selection from candidates or interested market parties in the context of the planned Tender;
- Market participants who do not apply for this market consultation will not be excluded from participating in the (possible) final Tender. Similarly, market participants who join this market consultation will not be excluded or privileged from participation in the (possible) final Tender;
- This market consultation is non-binding, both for the participants and for TNO;
- Parties who may or may not participate in this market consultation cannot derive any mutual obligations or rights vis-à-vis TNO;
- Participating to this market consultation does not confer no entitlement at obtaining a contract award;
- TNO shall not reimburse any eventual costs in participating to this market consultation;
- Participating market parties agree that the information provided by them can be processed anonymized in the further elaborating program of requirements;
- In the context of the market consultation, provided information may differ from the information that will be provided in the (possible) Tender procedure;
- The contribution of participating Parties will be handled as much as possible with confidentiality and in any case TNO will take into account the legitimate interests of the parties;
- The official language during this market consultation will be Dutch and/or English;
- TNO is in no way bound by the outcome of the market consultation or obliged to realise and/or put out to tender the desired investment to which the market consultation is linked;
- No claim will be honoured for the use of information, confidentiality, or request for compensation herewith;
- All documents submitted by the participating Parties are considered public documents and shall be copy-right free. If copyrights are applicable, TNO is protected by the participating Parties;
- No value judgment can be attributed to TNO's answers to questions given by you;
- TNO reserves the right to:
  - o perform the proposed procurement process in a different way, in terms of content and style, than the process that may have been communicated;
  - o to cease publication of the market consultation temporarily or permanently.
- Participating in this market consultation, constitutes the Parties unconditional approval of the procedure as stated in this document.

### 2.2 Form and content

The consultation is set up as follows:

#### 2.2.1 Written responses

Any interested market party who believes that they can contribute to the market consultation, should respond to the consultation document in writing, by e-mail. Responses should be received by TNO no later than [date]. Responses can be sent to:

Name : Arjan Verhoeven  
 Position : Senior buyer  
 Department : Procurement  
 E-mail : via TenderNed's question-and-answer module of the related Tender

The information received may lead to more in-depth questions for TNO. Optionally, TNO may therefore decide to hold a second round of in-depth questions. For this second round of in-depth questions TNO will only invite those parties who also participated in the first round. In addition, TNO leaves the possibility open to invite market parties without justified reasons and to ask for an additional explanation of the answers received.

#### 2.2.2 Language

Responses to this market publication must be submitted in the English language. Responses submitted in other languages than the English language will be excluded from further participation in this market consultation procedure. Evidential documents which cannot be submitted in the English language, can be submitted in the original language but the Tenderer should be able to provide a (sworn) translation on request.

**2.3 Intellectual property rights**

Subject to the exceptions provided for by law, nothing from this market consultation document may be reproduced (other than for the purpose of this document) in any form, by print, photocopy, DVD, CD-ROM, microfilm or other means, without the prior written permission of TNO.

**2.4 Use of TNO logo**

It is not permitted to copy, modify or otherwise use the TNO logo on any documents submitted by the Tenderer further to the Tender procedure.

### 3 Background

#### 3.1 Devices

TNO is fabricating and testing quantum computing device prototypes fabricated using silicon and silicon-germanium alloy-based semiconducting heterostructures with metallic gates for their electrical control. Figure 1 shows a top-down image and two side-view schematics for the types of quantum computing devices that are fabricated.

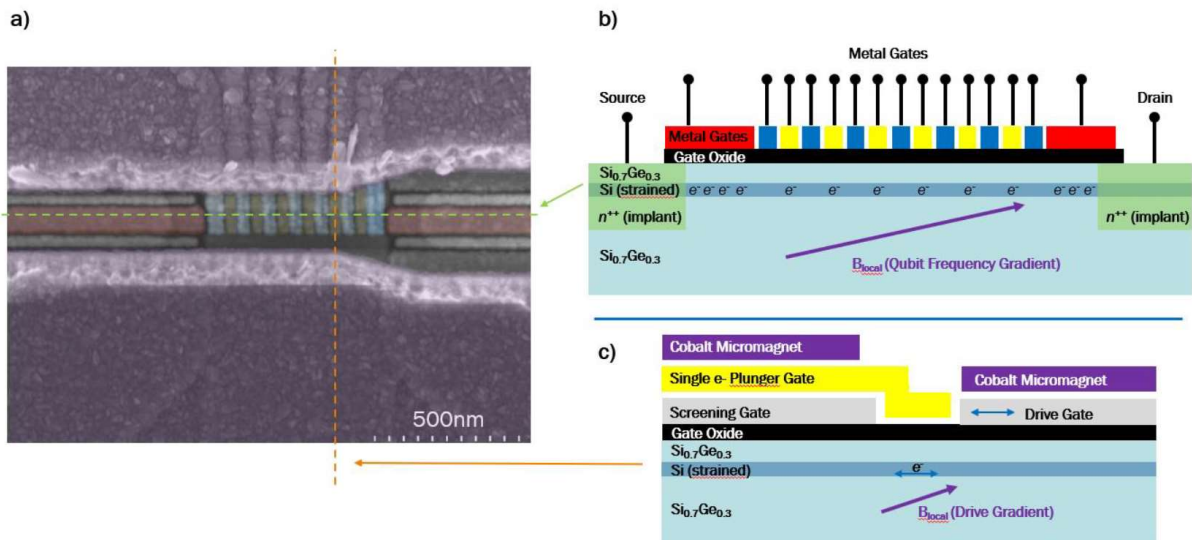


Figure 1: a) Top-down and false-color scanning electron micrograph 1) and cross-sectional schematic views b) and c) of QuTech's Spin-6 device: images were taken from the following publication: <https://doi.org/10.1117/12.2639994>, which is also available as a white paper here: <https://www.tno.nl/publish/pages/4062/verberk-2023-synergy.pdf>.

A larger image of a typical device with all of the fanout and contact pads can be seen in figure 2.

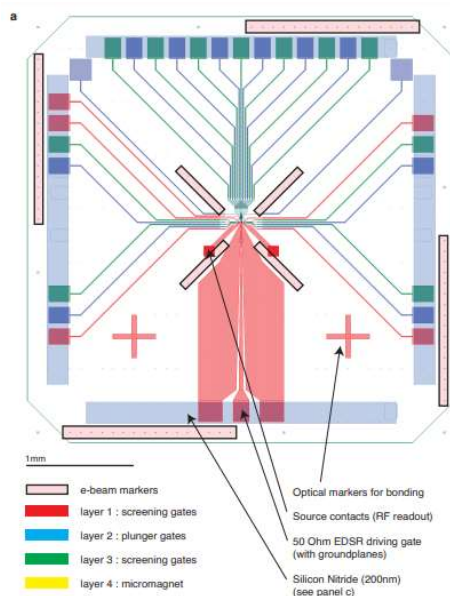


Figure 2: a) Top-down schematic of QuTech's Spin-6 device showing the fanout and number of bond pads for the current generation of devices. The number of bond pads and interconnect lines will only increase over time. The image is from the publication: <https://www.nature.com/articles/s41586-022-05117-x>, which is also available at the TU Delft repository: <https://research.tudelft.nl/en/publications/universal-control-of-a-six-qubit-quantum-processor-in-silicon>.

In order to improve the properties of these devices, QuTech researchers fabricate various test structures goaled to understand different material properties and design aspects of the quantum chips. Figure 3 shows a process flow for optimizing quantum computing device design and some of the various test structures fabricated during this process. These devices are fabricated at the 4" wafer level and then diced into smaller chips for testing.

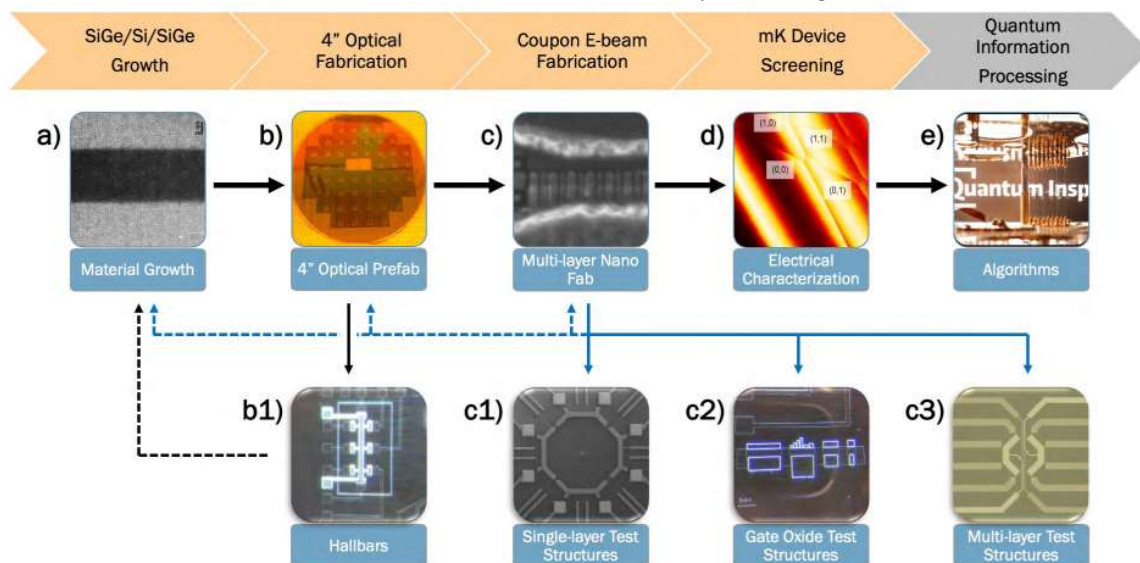


Figure 3: A process flow used at QuTech to evaluate new chip designs and materials used in the fabrication of spin qubit devices. This image is from the publication: <https://doi.org/10.1117/12.2639994>, which is also available as a white paper here: <https://www.tno.nl/publish/pages/4062/verberk-2023-synergy.pdf>.

Device testing currently involves equipment such as 1) a 200mm semi-automatic probe station operating between -40C and 200C with equipment such as an inductance capacitance and resistance meter (LCR) and a semiconductor device analyser (SDA), 2) a cryogenic dipstick operating at 4K where samples are wire-bonded to a PCB, and 3) various dilution refrigerators operating at ~10-40 mK. In order to more fundamentally understand the physics associated with the cryogenic performance of these device, TNO is interested in augmenting this infrastructure to include a multiple-use cryogenic sample prober operating down to ~6K for quantum computing devices and various test chips. This sample base temperature arises assuming a cryostat base temperature of around 4.5K, taking into account various losses. The closer the sample can get to 4K or even below, the better.

Of particular interest is the ability to cool samples down in darkness (or controlled light) while also under the application of voltages applied to selective regions on the device. Sample must be able to be contacted on both the top-side, with some form of metallic needle probes lowered onto the device, as well as to the backside of the device. Needle probes are necessary because certain devices (e.g., MOSFETs) involve measurement of the materials directly underneath the metallic contact pad, and electrical contact via wire-bonding would be too destructive to the material underneath the metal pad.

The probe station should not consume liquid He. TNO wants to invest in "cryogen-free" systems to avoid dependence on access to cryogenic gases.

### 3.2 Intended methods of use:

The main intended use of the cryogenic sample prober (CSP) is to investigate electrical material properties as a function of temperature. Measurements which can be expected, among others, are:

- Capacitance-voltage and conductance-voltage measurements on metal-insulator-semiconductor capacitors (MISCAP) and on metal-insulator-metal capacitors (MIMs).
- Measurements of voltages as a result of forced current through 4-point resistance, van der Pauw, or other structures.
- Measurement of currents as a result of forced voltages through MIM and MISCAP structures.
- Measurements on transistor devices: Id-Vg, Id-Vd, turn on voltage (VT), current on/off ratio, on-resistance, and subthreshold swing (SS), among many others.
- Measurement of the resistance of via-chain structures.
- Cryogenic screening (current and voltage measurements as described above) of devices with up to 40 bond pads, where there may be 14 or more bond pads along a single edge of the device.

- High frequency (GHz) circuit parameter measurements of transmission lines structures and device responses to GHz excitation (up to 40 GHz).
- Measurement of any of these properties as a function of exposure to light of selected frequency from IR to UV.
- Measurement of any of these properties as a function of temperature from 300K down to base temperature.
- Of critical interest is to be able to cool down devices under the application of a voltage to a particular region of the device without interruption during the cooldown process. This needs to be done with an electrical probe; a wirebond cannot be tolerated for reasons described above.
- Not all measurements need to be possible at a given time, but the system needs to be configurable to switch between different experiments within less than 8 hours of work.
- Devices for measurement are expected to be 20-25 mm in lateral dimension. Larger and smaller is also OK.

Measuring of device properties at base temperature will be regularly done, as well as temperature dependence studies ranging between ~6 K up to 300 K. It is desirable to be able to hold the cryogenic sample prober at an arbitrary temperature within that range for long times: e.g., up to a few days.

### 3.3 Material Analysis procedure:

To characterize our materials, we fabricate test chips along with our prototype product chips. We can define our own test devices, and tailor them depending upon the material parameters we want to investigate. Some examples are transmission lines, 4-point resistance or van der Pauw structures for metal lines, TLM structures, via-chain structures for evaluating via resistance, transistor structures, metal-insulator-metal (MIM) and metal-insulator-silicon capacitor (MISCAP) structures.

Occasionally, we glue multiple smaller devices to a carrier and mount this on a sample mount, supplied by the CSP manufacturer. In other cases, the sample of interest can be directly mounted on the sample mount using the appropriate cryogenic adhesives. This sample mount is located in the CSP, and allows electrical and optical access to the sample using reconfigurable probes. In some cases, the samples need to be in sufficiently good electrical contact with the sample mount such that voltages can be applied to the backside of the sample via the sample mount. In such cases, the sample mount where the sample resides needs to be electrically isolated from the rest of the CSP, but such electrical isolation should have as minimal as possible effect on the thermal properties (i.e., minimal rise in base temperature). As our devices are operated in the milli Kelvin temperature regime, the tested samples need to be cooled down to those temperatures as closely as possible.

When we start to measure a test sample, we first confirm whether we can make a low resistance electrical contact to the device using probe needles. After this, we will connect our measurement setup to the CSP and one of the aforementioned measurements will be performed, preferably using a script. The saved data (voltage, current, capacitance, impedance, phase angle, S-parameters, time, temperature, and frequency) is transferred and analyzed using a software of choice, including Python, Excel, Mathematica and/or others.

The sample will be loaded by opening the CSP main vacuum chamber and mounting it on the stage. Is it also possible to use a load lock system. After this, the chamber is closed and pumped down to minimize condensation of air on the sample during cooling. The sample and probes need to be viewed using a microscope with an integrated camera, but then exposure to light needs to be controlled as many electrical measurements, and transitions between measurement temperatures, will need to be in the dark.

After the system is closed and pumped down to sufficient vacuum needed to prevent condensation, probes can be landed on the sample after which electrical and possibly optical measurements can be performed. Electrical contact shall be transparent and confirmed. Then, the stage can be cooled down while continuously measuring parameters as a function of temperature in the dark or under controlled illumination conditions. The cooldown can be stopped at any temperature, where measurements as a function of multiple parameters can be performed, without having to change the light or dark condition.

The CSP should have a proper data interface. TNO should be able to take automated multi-parameter measurements as a function of temperature using scripts developed by TNO, QuTech, or others. For this purpose, temperature and pressure data of the CSP should be available to read out using a computer and integrated into a (e.g., python based) data acquisition framework of our own making.

Since most samples are ESD sensitive, the system should minimize the chance of electrostatic discharge through the device.

## 4 Clarification of the functional & technical desired requirements

### 4.1 Technical requirements

Below is a concise list of the desired cryogenic sample prober (CSP) specifications:

#### The probe controller

- 4.1.1 The CSP shall have at least 6 configurable probe arms or a configurable probe card with multiple tips as described below.
- 4.1.2 The 6 probe arms or probe card shall be installed and wired at delivery.
- 4.1.3 The CSP shall have at least 6 micromanipulated stages, one for each of the configurable arms for probe placement above the sample, or the probe card should have the ability to move probes to depending upon the device layout.
- 4.1.4 Each probe arm or probe card shall be properly shielded and cooled to sufficiently low temperature for proper measurement of devices.
- 4.1.5 The probe arms, or the probes on a probe card, shall be able to be independently positioned across a sample device region of 20-25 mm x 20-25 mm or larger (or a little smaller).

#### DC probes (for DC and AC measurements up to a few MHz)

- 4.1.6 Probes shall be able to maintain good electrical contact with the device over at least a 150K range of temperature (full temperature range from 300K down to base preferred) without the need to readjust contact or expose the sample to light.
- 4.1.7 Probes shall be connected with guarded cabling as necessary to measure low leakage currents (less than 100 fA) and to enable the measurement of small capacitances (e.g., > 1 pF).
- 4.1.8 DC electrical isolation of probes shall be more than 100 GOhm to enable measurement of device currents > 10<sup>-13</sup> A
- 4.1.9 Tip radii should be 25 um or less, ideally between 5 and 15 um.
- 4.1.10 A range of tip compositions, such as W or BeCu or others are desired for various device materials.
- 4.1.11 Probes should have coax or (ideally) triax connectors with proper feedthroughs
- 4.1.12 Probes shall compensate for thermal expansion and contraction in order to maintain good contact to the sample during warm up and cool down as necessary.
- 4.1.13 Probe arms that can deliver signals to up to 14 different pads in a linear array on the device are desired.
- 4.1.14 Methods to connect the ground/shielding between probe tips within the cryogenic environment as close to the sample as possible is desired for accuracy in CV curve measurement.
- 4.1.15 The series resistance and inductive impedance values up to the MHz range of the DC probes from feedthrough port to tip needle should be less than a few 10s of ohms.

#### RF probes

- 4.1.16 At least 2 probe arms that can deliver frequencies up to 40 GHz in a GSG arrangement with various pitch.
- 4.1.17 The series resistance from feedthrough to probe needle tip should not be more than a few tens of ohms; the lower the series resistance, within constraints of thermalization, the better.

#### Optical excitation

- 4.1.18 Controllable excitation of the sample with narrow bandwidth light in the range of IR to UV/VIS is desired in order to understand energetics of defects and their role in device operation.

#### Sample stage

- 4.1.19 Sample holder should be electrically isolated from the rest of the system so that desired voltages can be applied to the backside of the sample without ground loops.
- 4.1.20 Electrical isolation should not increase sample temperature more than 1-2 K above the base temperature.
- 4.1.21 Sample stage should be surrounded by sufficient radiation shielding but still have a way to view the sample and probe needles without heating up the sample above base temperature. After viewing the samples for contact purposes, the sample stage should be able to be kept in darkness.
- 4.1.22 Vibration should be less than 1-2 um
- 4.1.23 Some way to apply a magnetic field up to 0.2 to 0.3 milli Tesla is desired.

#### Temperature controller

- 4.1.24 The unit should be "cryogen-free" or "dry" in that no liquid helium is consumed during operation.
- 4.1.25 A base temperature of around 6K or below is desired.
- 4.1.26 Control of the temperature at arbitrary values between base and 300K for arbitrary time (at least 24 hours) is required.
- 4.1.27 A cooling power of around 1 W is desired at base temperature.
- 4.1.28 Temperature sensors should be placed at important locations within the CSP.

### **Vacuum system**

- 4.1.29 System shall be equipped with the proper vacuum system and computer control system in order to prevent any apparent sample condensation.

### **Measurement metrology:**

- 4.1.30 A microscope with proper zoom and lighting to see the sample and land the small probes in the right areas on the chip.
- 4.1.31 Calibration samples for use of RF is requested.
- 4.1.32 Calibration samples for stage and/or device temperature is needed.

### **Control:**

- 4.1.33 An instrument console to read out temperature sensors and to control the temperature of the probe station and vacuum system.
- 4.1.34 The instrument console and all control systems can also be controlled by python or a similar program.
- 4.1.35 The CSP should have its own software GUI for independent control and ease of use.

### **Lab environment**

- 4.1.36 The probe station and all its peripherals (e.g., probe station, compressor, gas tanks, vacuum pumps, instrument console, and monitors) should fit within a size of 2 m x 3 m.
- 4.1.37 While operating the system, it should consume less than 20 kWatt of electrical power.
- 4.1.38 There should be an instrument console that houses all equipment neatly.
- 4.1.39 The probe station can require compressed dry air and cooling water.
- 4.1.40 The cryoprobe station should have an operation lifetime of at least 10 years.

### **Safety**

- 4.1.41 The CSP shall be delivered with a manual which includes drawings and electrical layouts to perform simple troubleshooting and a basic operations guide.

## **4.2 Generic questions:**

### **Investment & Costs**

- 4.2.1 What would the cryogenic sample prober cost (the one-off costs; e.g. training personnel, acceptance tests, licence fees, etc.)?
- 4.2.2 What would the recurring costs be (support & maintenance, changes etc.)?

### **Development and implementation**

- 4.2.3 How much time would you need to manufacture the cryogenic sample prober for TNO?
- 4.2.4 What further insights are necessary for you to submit a correct bid?
- 4.2.5 What are potential bottlenecks in the manufacturing and realisation process?
- 4.2.6 Do you depend (partly) on third parties?
- 4.2.7 What is your experience with training personnel (instrument use, basic maintenance)?

### **Support and maintenance**

- 4.2.8 Please describe your delivery and support model for the required system?
- 4.2.9 How will you guarantee support for a long period of time (10+ years) on your products?
- 4.2.10 How would you deliver local support in the Netherlands for your products?