1 Mechanical Design

To gain insight into the behaviour of realistic metallic nanostructures, along with any chemical treatments or potential 'real world' applications, requires experiments be carried out in ambient conditions. Measurement of the physical properties of two nanostructures on the sub-nm scale in ambient conditions is a difficult challenge. For a microscope to be able to perform such measurements requires many careful considerations, the result of which is a compact experimental platform resistant to both vibrations and thermal effects.

The most important parts of any microscope are the sample stage and objective lens. For stable optical measurements these have to be locked together and mechanically referenced in a symmetric configuration to prevent mechanical or thermal drift between the sample of interest and the focal spot of the source. The short mechanical reference distance in an inverted microscope design provides the best stability and the microscope platform (Figure 1) is designed based on this concept. Mechanical drift is minimised by maintaining a close reference point between the sample and the objective. In this case the sample stage is tightly pocketed into a top plate from which the objective is screwed so that any vibrations between sample and objective occur in phase. Thermal drift is minimised by exploiting symmetry such that any expansion is around the objective and that all mechanical plates expand at the same rate. Cast aluminium is used for plate construction for its lower coefficient of thermal expansion compared to regular aluminium, whilst still remaining cheap and easily machinable compared to steel or titanium. The overall microscope platform is constructed 200 mm above the table on 1.5" diameter steel posts. The 200 mm height maintains stability without the need for cross-linking and is spacious enough to accommodate optics. The microscope platform and all important optics are mounted onto an anti-vibration stage to reduce vibrations. All optics are mounted in either cage or lens tube, held 5 mm off the table and locked together, for stability.

The typical experiment sample setup is shown in Figure 2a. Samples are mounted onto either of two 3-axis slip-stick translation stages with 12 mm of travel and fine piezo control (SmarAct GmbH, 2× SLC-1720-S with MCS), of which one is mounted onto a 3-axis piezo translation stage (PI GmbH, PI-733.3CD) for finer motion control. The top platform design is modular and easily removable, with a tight-fitting socket precise enough to relocate the sample stage to within 10 µm after removal. Multiple adapters are used to mount different samples onto the stage. A cover slip holder is used for nanoparticle characterisation while AFM chip holders (Figure 2b) are designed to mount tips. AFM probe mounts are made from machinable glass-ceramic (MACOR, Corning inc.) in order to prevent thermal expansion (good coefficient of thermal expansion $\alpha_{T,\mathrm{MACOR}} = 9.3 \times 10^{-6}\,\mathrm{K}^{-1}$, compared to other machinable materials' $\alpha_{T,\mathrm{aluminium}} = 23.1 \times 10^{-6}\,\mathrm{K}^{-1}$, $\alpha_{T,\mathrm{titanium}} = 8.6 \times 10^{-6}\,\mathrm{K}^{-1}$ or $\alpha_{T,\mathrm{ABS}} = 30.4 - -73.8 \times 10^{-6}\,\mathrm{K}^{-1}$ [**haynes2013crc**]) and to electrically insulate the mounts from the nanopositioners. The copper clamps holding the AFM probes are contacted to enable biasing

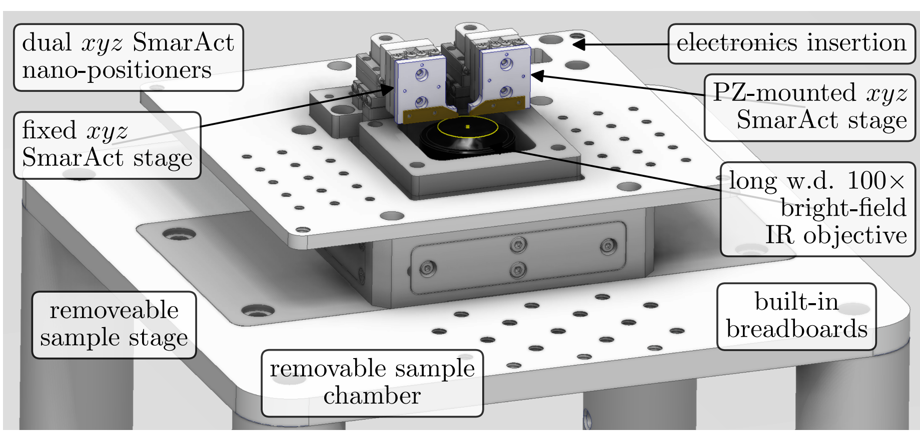

Figure 1: Mechanical design of the microscope. The main features of the inverted microscopy platform are highlighted, including two independent nanopositioners, one with piezo control, situated on a removable breadboard plate above the focus of an objective. Breadboard holes enable the mounting of optomechanics close to the sample. The top plate features a sealed lid with gas inlets for environmental control.

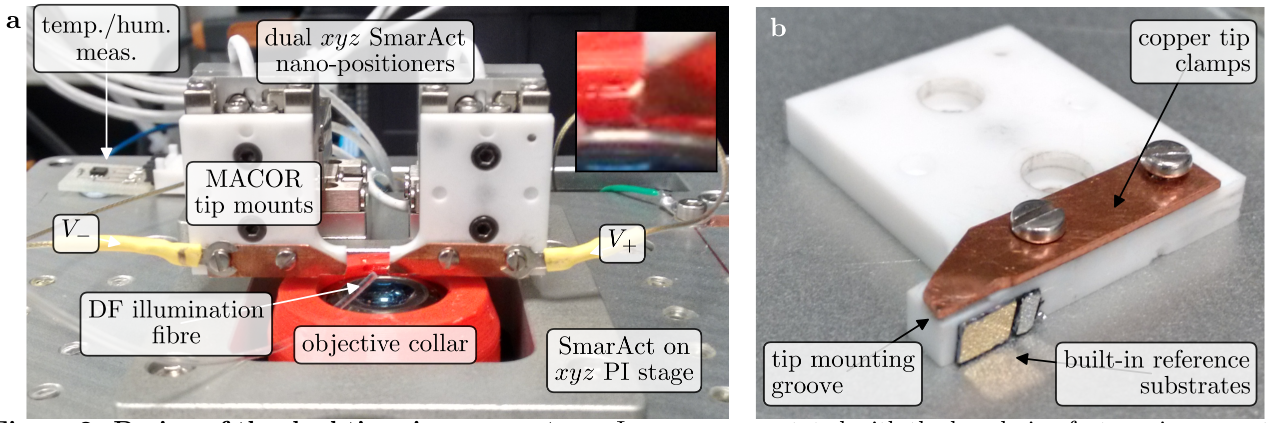

Figure 2: Design of the dual tip microscope stage. Images are annotated with the key design features incorporated into the sample stage. (a) Design of the dual tip mount stage and dark-field illumination mechanics. Each nanopositioner with tip mount clamp is connected to an external electronic circuit. A 3D-printed, plastic collar is attached to the objective, holding a 1 mm diameter optical fibre for dark-field side-illumination of tips. A temperature and humidity sensor is attached to the back of the plate for environmental monitoring when the chamber is sealed. (b) Design of the tip mounts. Tips are placed in a rectangular groove in the insulating MACOR plate and held in place by an angled Cu clamp. Electrode solder tags are screwed down onto the clamp to electrically contact the tip. Mirror substrates are stuck onto the bottom of the mount to provide an easily accessible, in-situ spectral referencing point for incident illumination.

of the junction between tips and measurement of the current through the junction.

The grounded experimental chamber is sealed to control the gas environment (switchable between a line containing air bubbled through water and a nitrogen line to control humidity) and act as a Faraday cage to reduce electromagnetic interference (EMI) incident on the sample. The chamber is equipped with a low pressure, one-way valve and a needle valve to control the gas flow. Silencers are attached to the gas inlets with a foam surround to prevent air currents. The presence of a sealed chamber is enough to stabilise the sample against external air currents and help maintain a constant thermal equilibrium around the sample. A low magnification basic microscope, constructed from a small CCD, is attached to the roof of the chamber to aid alignment of samples with the objective focus. Metal contacts connect the roof to the grounded base to form the Faraday cage. Optical windows on the sides of the chamber are used to insert secondary lasers perpendicular to the objective axis, used primarily with the AFM module. They also allow for external monitoring of the stage positions from the side.