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Mode Notes

High Voltage Toolkit

Atomic force microscopy (AFM) is a versatile tool for studying various material properties such as electrical, mechanical, magnetic, thermal, and electrochemical properties as well as surface morphology. Especially modes are commonly used that yield information of local electric properties like the surface potential, work function, conductance, or capacitance of the sample surface. All these modes require the ability to apply a bias between the sample and the cantilever tip during AFM imaging. Conventionally, a bias voltage between -10 V and +10 V is applied to study electrical properties of target specimens, but as recent research has diversified, an increasing number of experiments require applied potential above ±10 V. To address this demand, Park Systems developed the high voltage (HV) toolkit which enables an applied bias up to ±175 V. The HV toolkit can be used in conjunction with AFM modes that measure other electrical properties, such as HV Kelvin probe force microscopy (KPFM), HV Piezoelectric force microscopy (PFM), HV Conductive AFM (C-AFM), HV Scanning spread resistance microscopy (SSRM), and HV lithography. However, the HV toolkits require prudent insulation to prevent damage to other electric components of the AFM setup due to high voltages. Park Systems' AFMs address this issue using a specially designed

Figure 1. AFM components for system isolation. (a) isolated sample holder, (b) head extension module, (c) clip-type probehand and (d) front and backside of the isolated chip carrier.

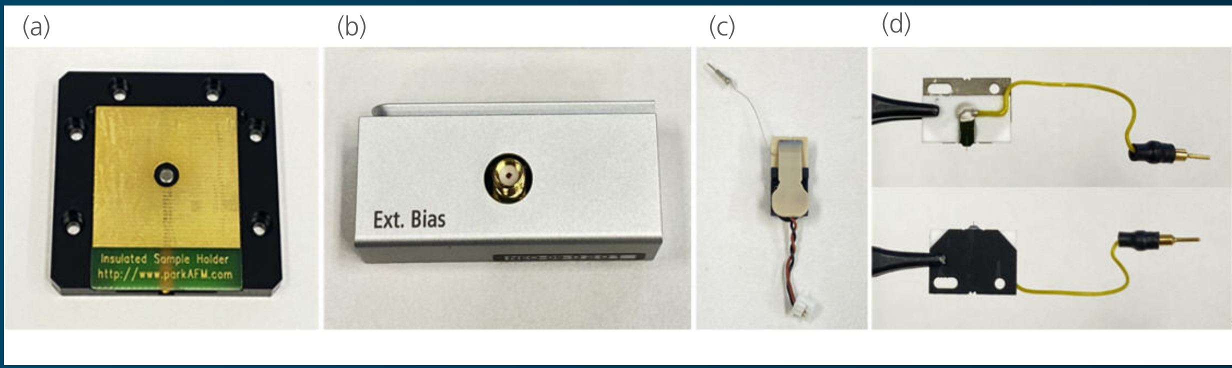


Figure 2. Photographs of 2 types of amplifier for HV measurements (a) type 1 and (b) type 2.

insulated sample holder (ISH) (figure 1 (a)), head extension module (HEM) (figure 1 (b)), and an AFM tip mounted on an insulated chip carrier using Teflon coating and a ceramic plate (figure 1 (d)). A clip-type probehand (figure 1 (c)) is also available for unmounted AFM tips.

An external current amplifier uses the standard bias voltage source of ±10 V provided by the AFM system as a feed signal and applies the amplified current directly to either the tip or sample via the HEM without passing the internal circuitry of the AFM.

Two types of voltage amplifiers are available

Table 1. Specifications of HV amplifiers.

	Type 1	**Type 2**
Amplification	20 ×	20 ×
Output bias range	-150 V ~ +150 V	-175 V ~ +175 V
Output noise	300 μVrms	4 mVrms
Power supply	Only 230V (AC)	24V ~ 30V DC (<120mA) DC power supplier required

Figure 3. (a) Design for HV lithography with gray color (Self-Portrait with Grey Felt Hat, Winter 1887–88. Van Gogh Museum, Amsterdam (https://www.vangoghmuseum.nl) and (b) PFM image after written by HV lithography. (PFM mode: DFRT-PFM)

for HV toolkit as shown in figure 2 with the respective specifications shown in table 1. Both HV amplifiers are controlled directly with the SmartScan™ software and enable adjustable amplification of the input current by a factor up to 20. For example, applying +2 V input voltage after setting the amplification value to 10 times in the SmartScan™ software will result in +20 V output to the tip or sample.

Figure 3 shows an example of the PFM measurement image after patterning a PZT surface with HV lithography. (see "Piezoelectric force microscopy mode note" and "Nanolithography mode note" for more information). Nanolithography patterns were written on the PZT surface using SmartLitho™ software with -40 V and +40 V applied to the bright and the dark area of the design, respectively (figure 3 (a)). Here, the positive and negative DC biases were applied via the tip and changed the polarization of the PZT surface domains to 180° angle. Subsequently, the rearranged domains were imaged with PFM as shown in figure 3 (b).

Figure 4 (next page) shows HV PFM mode measurements on Deuterated and L-alanine-doped TriGlycine Sulfate (DLaTGS) which is a high-performing material for pyroelectric detectors. At the position marked with the blue circle on figure 4 (a) and (b), hysteresis loops were measured with different sample bias ranges from -10 V to +10 V (figure 4 (c) and (d)) and from -40 V to +20 V (figure 4 (e) and (f)), respectively. As shown in figure 4 (c) and (d), no phase switching is observed within ±10 V sample bias range. In contrast, both up- and down-polarization are observed on the sample when using the HV toolkit. Here, switching occurs when applying a bias between -10 V ~ -15 V (figure 4 (e) and (f)).

Figure 4. PFM image and piezoresponse curve on DLaTGS Pyroelectric detector. (a) AFM height, (b) PFM image at 0 V sample bias, piezoresponse curves with ±10 V sample bias sweep range (c), (d) and with HV toolkit from +20 V to -40 V sample bias sweep range (e), (f), respectively.

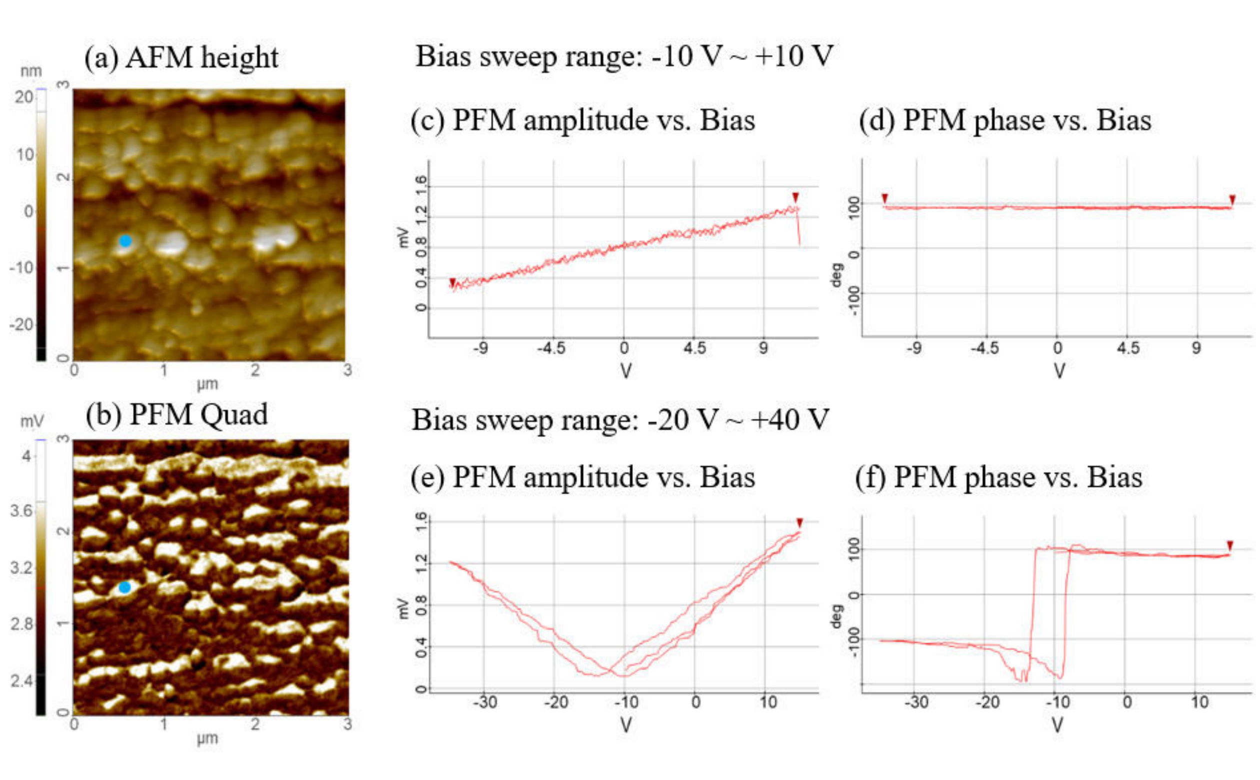
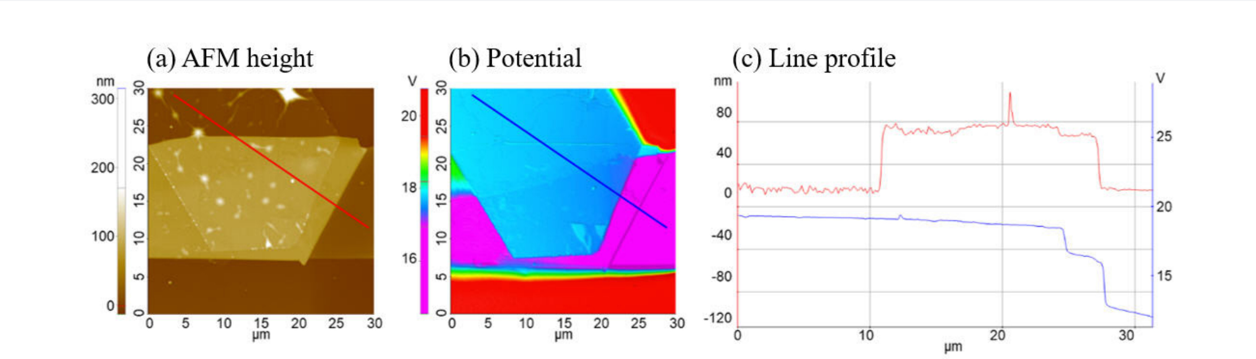
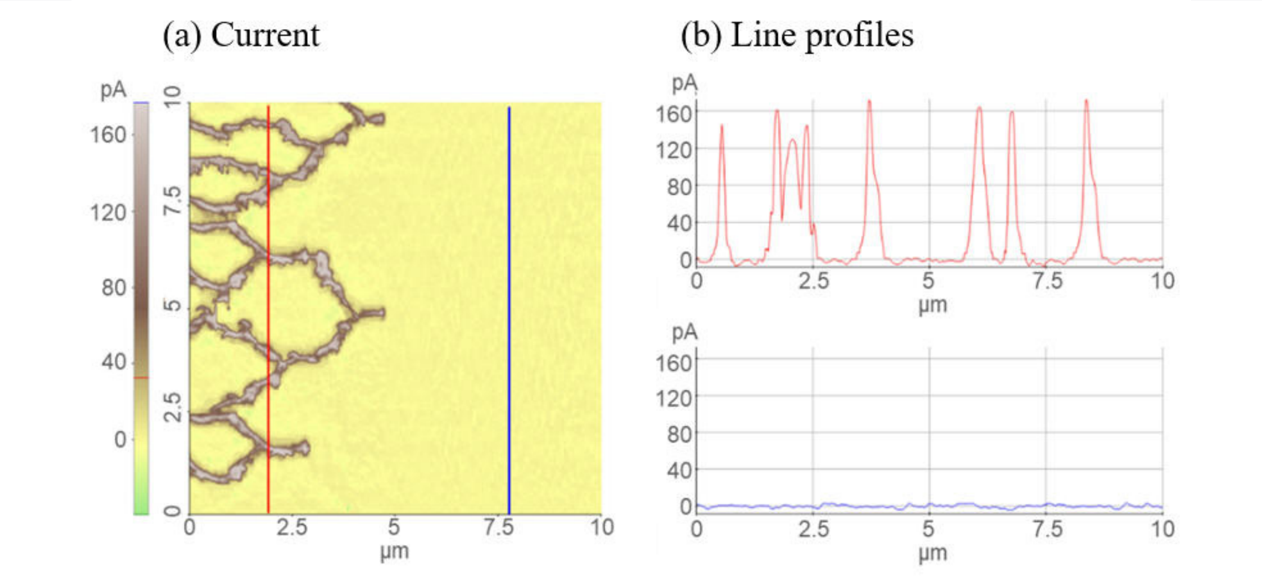


Figure 5. KPFM measurement with HV toolkit on MoS_2/hBN/MLG/SiO_2 sample. (a) AFM height, (b) surface potential image and (c) line profiles of height and surface potential on the sample.



The HV toolkit can also be used to expand the capabilities of KPFM, where surface potentials are usually detected up to a limit of ±10 V potential with the standard setup. Here, the tip-bias feedback range can be extended with two additional HV amplifiers; one for sample bias amplification and the other for tip bias amplification. Figure 5 shows an array of MoS_2/hBN/multi-layer graphene (MLG) on a SiO_2 substrate and their respective surface potentials observed with KPFM measurement while applying +20 V to the sample. When comparing the height image with the potential image in figure 5 (a) and, it can be observed, that not every layer affects the measured surface potential equally. Here, the impact of

Figure 6. Current measurement with HV toolkit on ceramic coated Si device. (a) Current and (b) line profiles.



the top layer on the local surface potential is overcompensated by the influence of the bottom layers.

Another example of HV toolkit application is for leakage current measurement. Figure 6 shows the current measured while applying +70 V sample bias using HV toolkit to a ceramic coated Si sample. A few pA of current is observed on an intact coating sample, whereas defect areas exhibit current peaks over 160 pA.

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