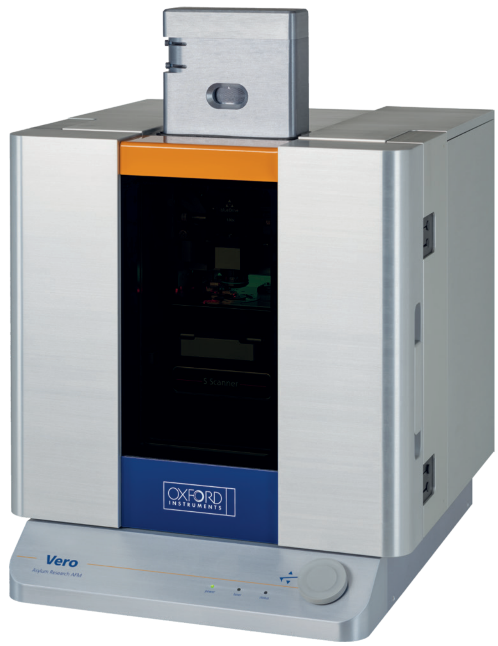
ASYLUM RESEARCH

Vero: AFM Redefined

First and only AFM with QPDI cantilever sensing technology

Vero is a next-generation AFM from Oxford Instruments Asylum Research that precisely and accurately measures true tip displacement using Quadrature Phase Differential Interferometry (QPDI). Until now, AFMs have relied on optical beam detection (OBD), which actually measures cantilever angle, not tip displacement. This distinction is important for AFM techniques that rely on quantitative analysis of tip motion. Vero builds on the unrivaled stability and performance of the Cypher AFM family and is the first and only AFM to feature QPDI cantilever sensing technology. This unique patented innovation enables Vero to provide AFM results with higher accuracy, precision, and repeatability.



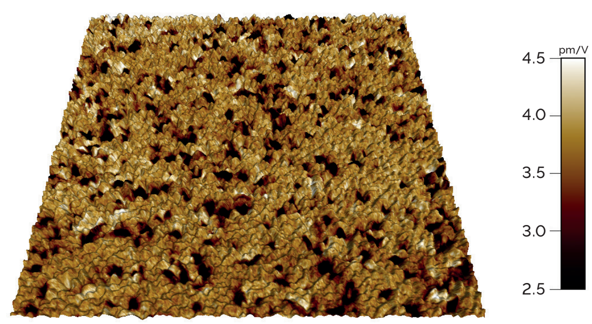
Vero enables more accurate and repeatable AFM results because QPDI:

Measures true tip displacement
- QPDI directly measures true tip displacement instead of cantilever angle, enabling improved quantification of many AFM measurements

Improves measurement sensitivity
- QPDI lowers cantilever detection noise by a factor of up to 10× or more on many cantilevers, enabling improved measurement sensitivity

Avoids crosstalk between vertical and in-plane forces
- Only QPDI measures pure vertical tip displacement, avoiding the large crosstalk between ODB vertical and lateral deflection signals

Is precisely calibrated by the wavelength of light
- Interferometric detection avoids the assumptions and uncertainties associated with OBD calibration

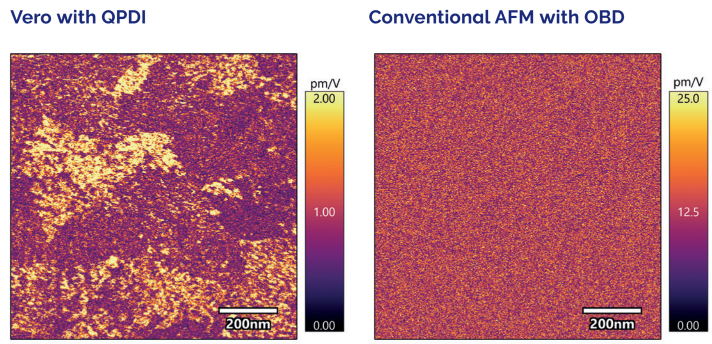


Piezoresponse force microscopy (PFM) is one mode that especially benefits from the advantages of Vero QPDI cantilever sensing. Here, a scandium aluminum nitride film was measured using single-frequency PFM on Vero to measure the effective piezoelectric coupling coefficient of the material. Grain defects in the film exhibit much lower piezoelectric response than the rest of the film. Scan size is 5 µm. Additional results are presented on page 3. (Sample courtesy of Agnė Žukauskaitė and Stephan Barth, Fraunhofer FEP, Germany).

Lower Noise = Improved Measurement Sensitivity

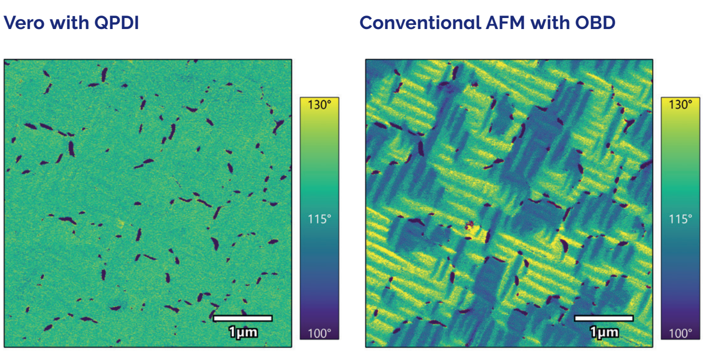
Lower noise detection of the cantilever displacement improves measurement sensitivity for modes including PFM. The figure on the right shows an example where PFM was used to study hafnia, a ferroelectric material being developed for data storage applications. The lower detection noise on Vero allowed the clear measurement of piezoelectric domains, while the response was well below the noise floor of a conventional AFM using OBD. Vero enables PFM measurements to be made in single-frequency mode without the added complexity of resonance enhancement or the need to use high-voltage biases.

The noise performance of the QPDI detector is exceptional for both low frequencies (e.g. for forces curves and force mapping) and the higher frequencies where PFM and tapping mode-based techniques operate. Unlike OBD, the QPDI noise performance does not depend on the cantilever length, so the optimal probe can be chosen based on other criteria.



Hafnia piezoelectric response measured by single-frequency PFM

Hafnia exhibits an ultra-low piezoelectric response that makes it challenging to measure with PFM. As shown on the left, the sensitivity of Vero enables the clear resolution of piezoelectric domains. But as shown on the right, on a conventional AFM with OBD the response is completely obscured by its much higher noise floor. (Sample courtesy of NamLab, Germany).



Bismuth ferrite PFM phase images

BFO is a multiferroic material with complex domain structure that exhibits both out-of-plane and in-plane piezoelectric response. Unambiguous characterization has been challenging with PFM on conventional AFMs because of crosstalk between vertical and lateral OBD deflection signals. Using QPDI detection on Vero (left), the material exhibits highly uniform out of plane polarization. However, the same area imaged with an OBD-based AFM shows highly variable polarization, despite being calculated from the "vertical" OBD deflection signal. (Sample courtesy of Ying-Hao Chu, National Tsing Hua University, Taiwan).

Avoid Artifacts Caused by OBD Crosstalk

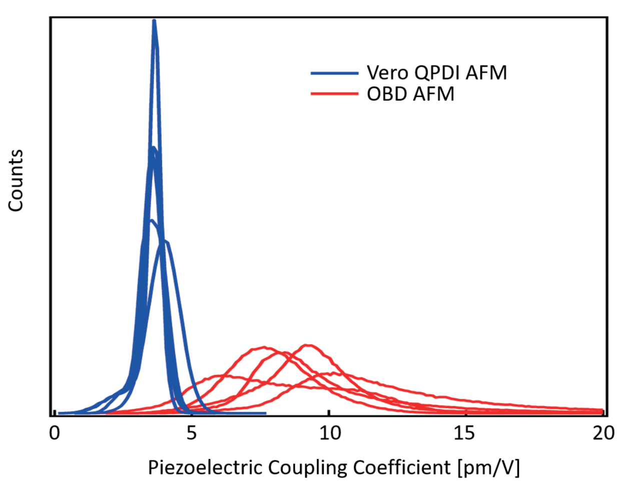
The QPDI detector on Vero measures the pure vertical tip displacement without crosstalk caused by in-plane forces. While OBD-based AFMs usually output both vertical and lateral deflection, there is significant crosstalk between these signals because of the complex way that these forces affect cantilever bending. The figure on the left shows PFM phase images of bismuth ferrite (BFO), a multiferroic material. Vero can isolate just the vertical response and demonstrates that this BFO sample has uniform out-of-plane polarization. The same area imaged with a conventional OBD-based AFM shows complex structure attributed to the in-plane response of the material.

While the QPDI is normally configured to measure just the vertical tip displacement, the same light beam on Vero also generates conventional OBD deflection signals, which can be used to augment the QPDI signal.

Vero: More Accurate and Repeatable Results

By directly measuring tip displacement using QPDI, Vero enables measurements to be made while avoiding some common measurement artifacts. One such artifact occurs in PFM when electrostatic forces between the sample and cantilever contribute to the bending of the cantilever. When using OBD, this additional bending is incorrectly interpreted as tip displacement because OBD cannot distinguish between different contributions to bending. This distorts PFM measurements, leading to poor accuracy and repeatability. Since QPDI can measure tip displacement without any influence from cantilever bending, it avoids this common artifact.

The overall accuracy and repeatability of Vero results are improved by all the factors presented here: lower noise, crosstalk reduction, direct tip displacement measurement, and precise interferometric calibration. The example below illustrates the difference between OBD and Vero QPDI for a real-world PFM measurement. Aluminum scandium nitride is a commonly used piezoelectric material in RF filters. The histograms represent five different measurements made with each technique. To mimic the variations in real scan conditions, each was made using the same sample but different probes, drive amplitudes, and scan angles. One readily sees that the OBD measurements exhibit both much broader distributions within each measurement and much more scatter between the averages of the measurements. The Vero QPDI results, however, are far more repeatable and have much narrower distributions.



Comparison of Vero and OBD PFM on AlScN (~30% Sc)

Single-frequency PFM amplitude images were measured under different conditions using a conventional AFM and Vero. Vero results show far better repeatability and narrower distributions. (Sample courtesy of Agnė Žukauskaitė and Stephan Barth, Fraunhofer FEP, Germany).

Brief Introduction to QPDI Technology

Interferometric detection was common for several years after the invention of AFM before being displaced by the simpler to implement OBD method. Those early interferometric AFMs were complex and suffered disadvantages, including limited cantilever detection range, poor low frequency noise performance, and obstructed optical view of the sample. These issues have been fully eliminated by the novel QPDI design in Vero. While a full description of QPDI is beyond the scope of this datasheet, two features are important and can be readily understood.

The "quadrature phase" aspect of QPDI is what allows it to measure displacement with ultra-low noise even for large displacements. Unlike less sophisticated designs, QPDI is not limited to displacements much smaller than the wavelength of light.

The "differential" feature of QPDI is what enables it to achieve ultra-low noise at low frequencies as well as high frequencies. Interferometers compare the light beam reflected from the measurement surface to one reflected by a reference surface. More basic designs placed this reference far from the cantilever, leading to significant drift and low frequency noise. With Vero QPDI, the reference surface is the back of the cantilever chip, which leads to superior performance.

For an in-depth review of QPDI, read our tech note here:

To learn more about Vero benefits specific to PFM, read our application note:

Also accessible from AFM.oxinst.com/Vero

Vero Specifications

Scanner

Vero is available with either the “S” standard scanner or the “ES” scanner, which enables support for environmental control accessories. Both scanners share these specifications.

X&Y range 30 µm (closed-loop)
X&Y sensor noise <60 pm
Out of plane motion <3 nm in Z over XY range
Z range >5 µm
Z sensor noise <50 pm
Sample size up to 15 mm diameter, 7 mm thick. Samples can be moved using software-controlled stick-slip motion.
Engage process Using software controls, the user focuses on the tip and then the sample to find the approximate separation distance. An automatic motorized process then takes over to engage quickly and without damage to the tip.

Cantilever Sensing

Vero uses QPDI as the primary cantilever sensing detector but also incorporates an auxiliary OBD sensor to enable conventional vertical and lateral deflection signals.

QPDI detector noise <10 fm/rtHz
Wavelength 650 nm
Spot size <4 µm
Detector bandwidth DC to 7 MHz

QPDI noise performance is optimized for cantilevers with reflective coatings but, unlike OBD noise, QPDI noise does not depend on the cantilever size. While OBD noise can range by a factor of 10 or more depending on cantilever size, the QPDI detector noise is consistent across all cantilever sizes.

Spot positioning and detector adjustment are fully motorized and software controlled.

Imaging Performance

DC height noise <15 pm
AC height noise <15 pm

Top-view Bright-Field Optics

Resolution Diffraction limited (<1 µm), NA=0.45
Field of view 600×800 µm
Illumination Intensity is software controlled. Manual controls for the aperture and field diaphragms.

(All noise measurements are quoted as the average deviation measured with a 1 kHz bandwidth over a full 10 seconds at the center of the scanner range. Specifications assume required vibration and acoustic isolation in an appropriate laboratory environment.)

Instrument Isolation

Vibration <10 pm coupling into deflection for 1 mm/s^2 floor acceleration when using just the built-in passive isolation. No further isolation is necessary for typical laboratories.
Acoustic Included enclosure provides 20 dB of isolation.

Included Operating Modes

Contact mode; DART PFM; Dual AC; Dual AC Resonance Tracking (DART); Electric force microscopy (EFM); Force curves; Force mapping mode (force volume); Force modulation; Frequency modulation; Kelvin probe force microscopy (KPFM); Lateral force mode (LFM); Loss tangent imaging; Magnetic force microscopy (MFM); Nanolithography and nanomanipulation; Phase imaging; Piezoresponse force microscopy (PFM); Switching spectroscopy PFM; Tapping mode (AC mode); Vector PFM

Optional Operating Modes

AM-FM Viscoelastic Mapping Mode; Contact Resonance Viscoelastic Mapping Mode; Fast Force Mapping Mode (FFM); Conductive AFM (CAFM); Current mapping with FFM; Electrochemical Strain Microscopy (ESM); High voltage PFM; Nanoscale Time Dependent Dielectric Breakdown (nanoTDDB); Scanning Capacitance Microscopy (SCM); Scanning tunneling microscopy (STM)

Other Options and Accessories

blueDrive photothermal excitation is available.

Liquid imaging options are available on both Vero S and ES configurations. The ES configuration includes a fully sealed sample chamber and options for liquid perfusion.

The Vero ES configuration supports most of the same environmental control accessories as Cypher ES. Please inquire for details.

Service and Support

Warranty One-year comprehensive warranty.
Support Ask about service and support agreements that extend the original warranty and offer additional training and support services.

Regulatory Information

Vero is CE compliant.
Vero is a Class 1 laser product