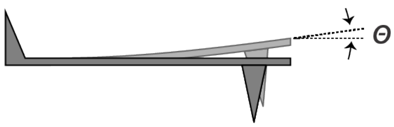
Interferometric Displacement Sensor Option for the Cypher AFM

Asylum Research

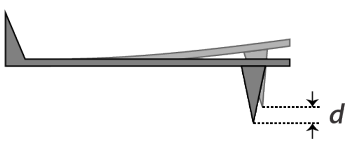
The Asylum Research Interferometric Displacement Sensor (IDS) Option adds an independent, quantitative measurement of cantilever displacement to the Cypher AFM, complementing the standard optical beam deflection (OBD) method. OBD is commonly used in commercial AFMs; it is relatively easy to implement and impressively quiet across a wide dynamic range. However, it is fundamentally proportional to angular changes rather than displacement, and interpreting the tip displacement requires an accurate model of the cantilever mode shape. While sufficient for some AFM measurements, it can lead to errors in others. The IDS addresses this shortcoming, providing a complementary, quantitative measurement of cantilever displacement during all dynamic measurement modes.



The OBD measures **angle, *Θ***

Standard optical beam deflection:

- Quantitative deflection requires calibration
- Calibration assumes cantilever mode shape
- These assumptions can fail, especially in contact modes



The IDS measures **displacement, *d***

Interferometric Displacement Sensor:

- Displacement sensitivity is intrinsically calibrated by the wavelength of light (λ = 632.8 nm).
- Compatible with all dynamic AFM modes (>1 kHz)

The IDS option does not interfere with the standard OBD measurement or other normal functions of the AFM. The IDS detection laser can be located anywhere in the field of view: on the cantilever or the sample, or programmed to step through a series of locations. The technology can therefore be employed in a wide variety of measurements, from quantitatively characterizing material properties, to improving our understanding of cantilever dynamics and the limitations of traditional AFM measurement modes.

The IDS Option quantifies the "last axis" in atomic force microscopy.

Types of Applications	Modes and Measurements
Quantitative Material Characterization Modes The OBD signal can be misinterpreted when the cantilever deviates from its expected or modelled shape. In contrast, the IDS provides an absolute measure of cantilever amplitude and deflection.	• On- and off-resonance contact techniques • Multifrequency techniques • Fast force mapping • Experiments in viscous media • Characterization of the tip-sample contact stiffness
Accurate Cantilever Calibration OBD-based calibrations rely on assumptions about cantilever mode shape. In contrast, the IDS can directly calibrate the stiffness and sensitivity of the first and higher flexural modes.	• Stiffness and sensitivity of higher eigenmodes • Quantitative lateral/torsional modes
Mapping Thermal and Driven Mode Shapes The IDS spot can be programed to step along the length and breadth of the cantilever, allowing an accurate measurement of the true cantilever mode shape during dynamic measurements.	• Quantify the effects of cantilever modes on regular AFM experiments • Test theoretical cantilever physics models

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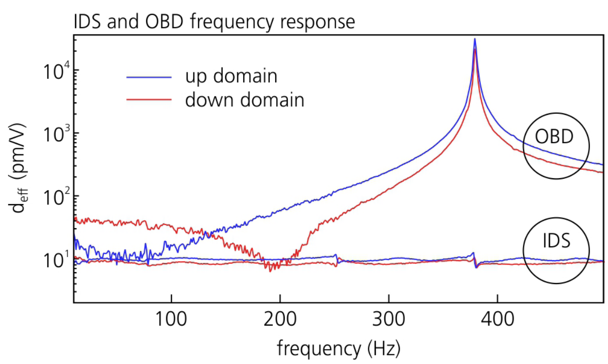
Applications in Electromechanics

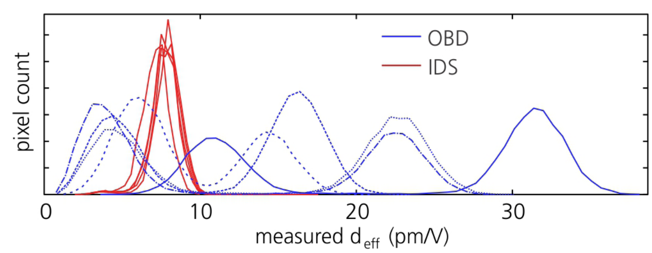
Piezoresponse Force Microscopy (PFM) is a powerful tool for nanoscale imaging, spectroscopy and manipulation of piezoelectric and ferroelectric materials. Nevertheless, and despite significant efforts, it can still be a challenge to quantitatively resolve the true coupling between a material's electrical and mechanical phenomena at these very short length scales. A Periodically Poled Lithium Niobate (PPN) test sample is a useful model system for exploring the origins of measurement artifacts in electromechanical measurements.

Characteristics of the PPLN Test Sample

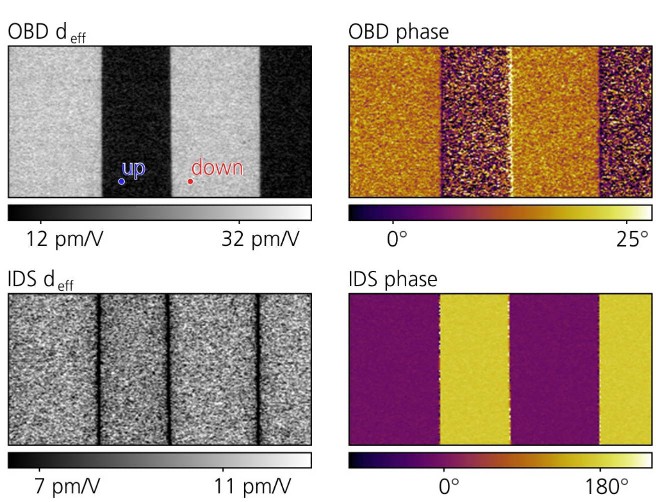
1. **Frequency-independent response:** The small size of the periodically poled domains means their ferroelectric response is significantly faster (~GHz) than the bandwidth of the AFM measurement.
2. **Phase shift of 180° across oppositely polarized domains:** Domains are oriented perpendicular to the sample surface.
3. **Amplitude independent of polarization direction:** Because of sample symmetry, the "up" and "down" domains should give the same amplitude of response.



Characteristic 1: Frequency Independent Response *(above): Simultaneous OBD and IDS measurements of the effective piezoelectric sensitivity, d_{eff}. The frequency response of the OBD measurement is dominated by cantilever dynamics: it varies by a factor of 1000 X, while the IDS measurement is nearly frequency independent.*

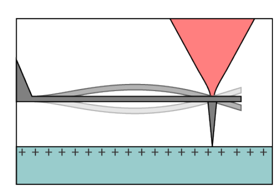


Characteristic 4: Quantitative Measurements Are Repeatable *(above): The graph shows the results from five different cantilevers. The histograms of the effective piezoelectric sensitivity, d_{eff}, derived from the OBD channel (in blue) show variations of an order of magnitude, and the results from each measurement has two maxima, originating from the "up" and "down" domains. In contrast, the results derived from the IDS measurements show consistent results for piezoelectric sensitivity (in red), with no dependency on domain direction.*



Characteristics 2 and 3: Phase Shift Is 180° and Amplitude Does Not Depend on Polarization Direction *(above): Effective piezoelectric sensitivity d_{eff} and phase domains measured simultaneously by OBD and the IDS. The IDS channel correctly shows the amplitude is the same and the phase is 180° out of phase in the oppositely poled domains. Drive frequency: 25kHz. Scan size: 5 µm x 10 µm.*

What's Going On?

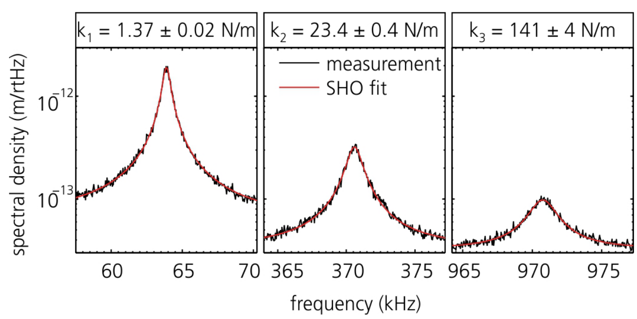


The IDS is ***only*** measuring the electromechanical response of the sample. That is, it measures the displacement due to the expansion or contraction of the sample only.

In contrast, OBD measures the cantilever's angular changes. In the case of these electromechanical measurements, electrostatic interactions between a charged sample and the body of the cantilever cause cantilever vibrations that are unrelated to sample movement. These vibrations are amplified by the cantilever resonance resulting in a strong frequency dependence that overwhelms the signal of interest. [Appl. Phys. Lett. **106**, 253103 (2015)]

Spring Constant Calibration

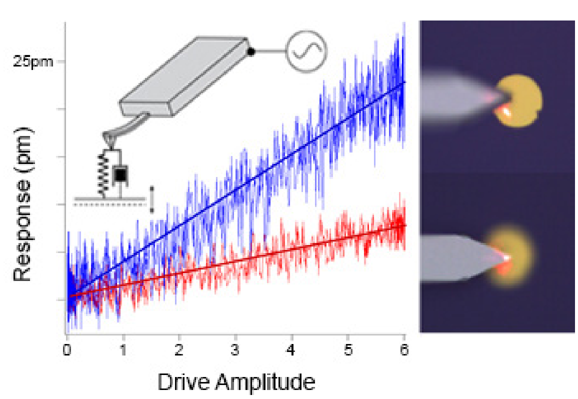
Multimodal techniques employ two or more cantilever flexural modes to quantitatively map material viscoelastic properties, extending the need for accurate cantilever calibration to higher eigenmodes. IDS can simply and accurately characterize the stiffness of any eigenmode (up to 2.5 MHz) for any type of cantilever.



Above: IDS calibration of cantilever spring constant *for the first three eigenmodes of an Olympus AC240 cantilever using the thermal method. These stiffness measurements are based on the wavelength of light, and don't require any assumptions or measurements of the cantilever geometry or its mode shape. [Appl. Phys. Lett.* ***87****, 073705 (2016)]*

Tip-Sample Contact Mechanics

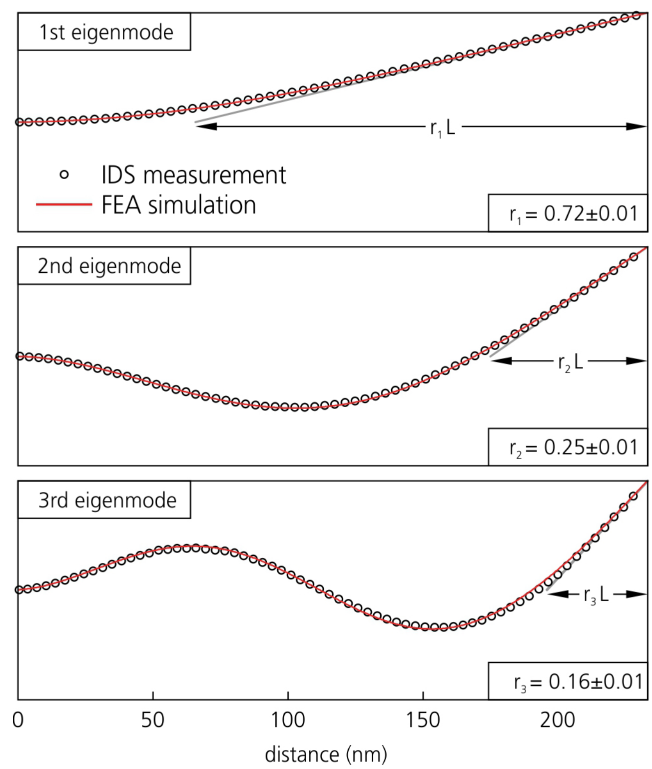
Quantitative mechanical or electromechanical property measurements require an accurate model of the tip-sample contact stiffness. The IDS allows comparisons between the sample movement and the cantilever displacement, with the difference between the two defining the stiffness of the contact.



Above: Tip-sample stiffness effects in piezoelectric sensitivity measurements. *The IDS was used to measure the true displacement of the gold pad (blue) and the cantilever (red). The gold pad is the top surface of a lead zirconate titanate device. In this experiment, it is actuated by applying a bias through the cantilever. The cantilever is moving only 50% relative to the sample expansion indicating that at this load, the contact stiffness is roughly equivalent to the cantilever stiffness.*

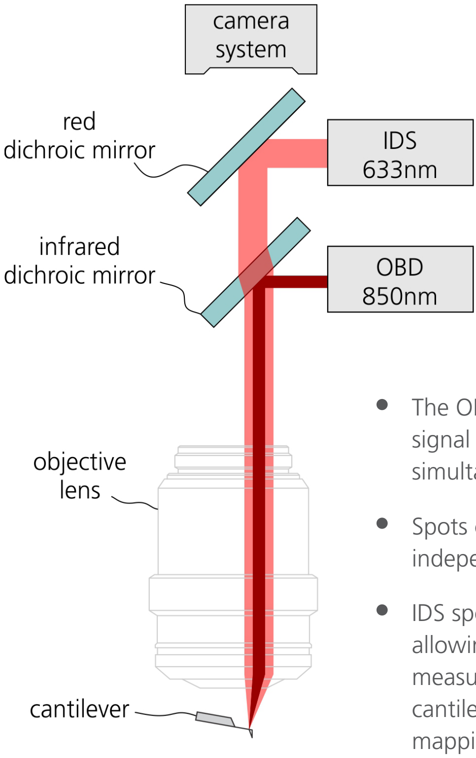
Mode Shape Mapping

Quantitative, dynamic material property mapping techniques are only as accurate as the characterization of the vibration mode. For any given experiment there are many factors that can result in a deviation from an expected cantilever mode shape: non-uniformities in the dimensions or stiffness of the cantilever, poorly characterized cantilever drag (from operating in liquid), or poorly characterized loading (due to interactions with the sample surface). IDS can be used to quantitatively measure the mode shape of any type of AFM cantilever in any type of medium.

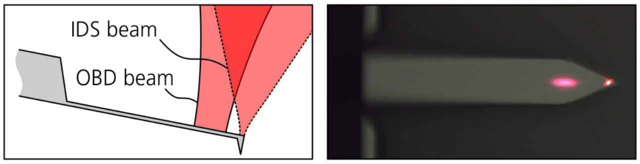


Above: IDS measurements *of the first three eigenmodes compared with finite element analysis simulations for an Olympus AC240 cantilever. This is a typical cantilever used for tapping mode imaging in air: the cantilever geometry is not uniform along its length, and the tip is set back from the end of the cantilever – see image below. These characteristics, among others, contribute to deviations from Euler-Bernoulli behavior. [Appl. Phys. Lett.* ***87****, 073705 (2016)]*

Integration and Specifications



- The OBD and the IDS signal are measured simultaneously.
- Spots controlled independently
- IDS spot < 3 µm allowing highly localized measurements, or cantilever mode shape mapping.



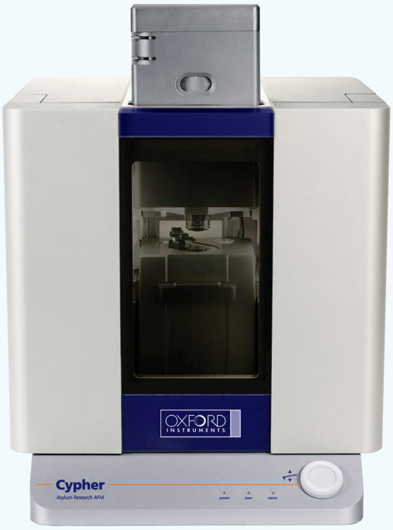
The IDS interfaces the Cypher AFM's existing optical system with an external laser Doppler vibrometer. It does does not alter or interfere with the standard functions of the instrument.

Specifications

- Operational bandwidth: 1 kHz to 2.5 MHz
- Detection noise floor: < 200 fm/rtHz (> 10 kHz)
  < 100 fm/rtHz (> 100 kHz)
- Largest measurable amplitude: > 1 µm
- Required cantilever reflectivity (@633 nm): > 80% (in order to meet specifications)
- Laser spot size: < 4 µm (1/e^2 diameter of circular spot)
- Spot positioning range: > 500 µm × 500 µm (software controlled)
- **NOT compatible with blueDrive**

Measurement Modes

- Electromechanics
  - Piezoresponse Force Microscopy
  - Electrochemical Strain Microscopy
- Nanomechanics
  - AM-FM Viscoelastic Property Mapping
  - Contact Resonance AFM
  - Fast Force Mapping
  - Nanorheology
- Dynamic (AC) Force Measurements
- Sub-resonance dynamic Measurements
- And more!



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6310 Hollister Avenue
Santa Barbara, CA 93117
Voice +1 (805) 696-6466
Toll free +1 (888) 472-2795
Fax +1 (805) 696-6444

www.oxford-instruments.com/AFM
AFM.info@oxinst.com