COVALENT
Material Insights

CASE STUDY

When "Clean" Isn't Clean Enough

Photoinduced Force Microscopy (PiFM) for Molecular Identification of Contamination on Photomasks

Introduction

Photoinduced Force Microscopy (PiFM) combines Atomic Force Microscopy (AFM) and IR to identify nanoscale residues and impurities on photomasks that must be exceptionally clean.

Photomasks are designed to be optically perfect and chemically clean, yet real-world handling, cleaning, pellicle processes, packaging, and fab environments can leave behind trace organic films or microscopic particles. When a defect is found, the fastest path to resolution is often chemical identification: is it resist residue, a cleaning byproduct, a silicone/siloxane transfer, or something else? PiFM is built to address this issue.

PiFM Capabilities

- PiFM is a non-contact mode technique to gently scan defects and characterize molecular identification.
- Semi-automated scanning and IR spectra collection routines to locate and identify defects from KLARF files.

PiFM at Covalent

Covalent recently added PiFM capabilities to support photonics and semiconductor customer applications that require molecular identification at the nanoscale.

Molecular Vista – Vista 200

- Scan head has dual z feedback system with 10 micron range high z + 100 nm low z feedback.
- Feedback operates in non-contact mode.
- **Lateral Resolution:** ~5 nm
- **Stage Travel:** 200 mm x 200 mm
- **Maximum Scan Size:** 120 µm x 120 µm
- **PiF IR Laser:** QCL (770–1840, 1995–2395 cm^{-1}), 1 cm^{-1} spectral resolution
- **Depth Probed:** ~30 nm in surface mode and can be greater than 100 nm in bulk mode.

How PiFM Works

PiFM is an AFM technique with IR functionality. A feedback laser (blue) is aligned onto a metallized cantilever while the IR laser (red) is focused on the apex of the tip. A highly localized enhanced field generates a hot spot at the tip apex (see figure 2), which allows simultaneously scanning topography and the photo-induced force chemical map with a lateral resolution of ~ 5nm.

The tip measures a photo-induced force (PiF) when molecules absorb infrared (IR) light at specific wavelengths. The IR laser is a highly tunable mid-IR that covers the fingerprint region of the IR spectrum (2395 cm^{-1} – 770 cm^{-1}). When the tip is parked over a defect, the laser sweeps through its frequency range and a PiF-IR spectrum is collected, which provides a molecular fingerprint.

If you set the laser to one wavelength, PiFM gives a map:

"Where on the surface absorbs this wavelength?"

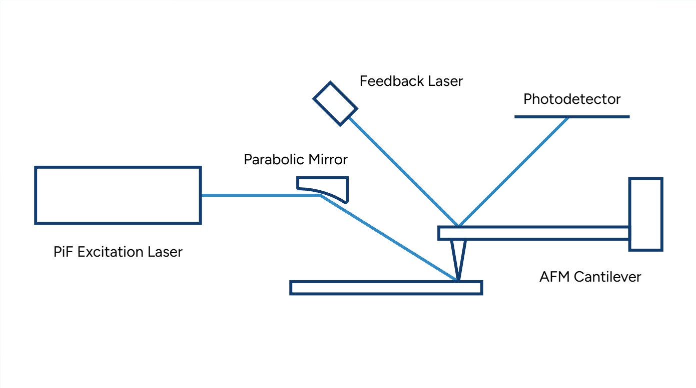

Figure 1: Basic principles of PiFM

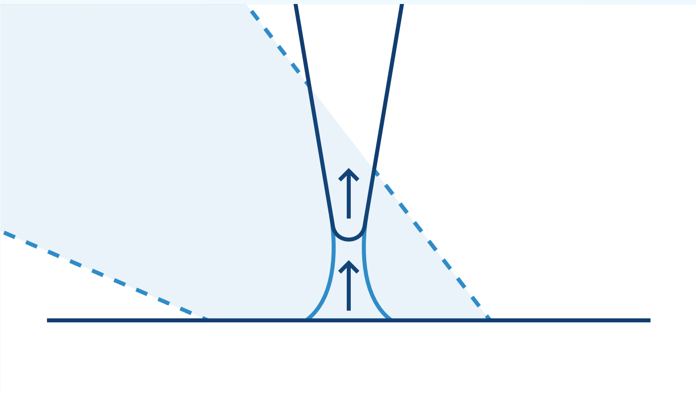

Figure 2: Localized Field-Enhancement

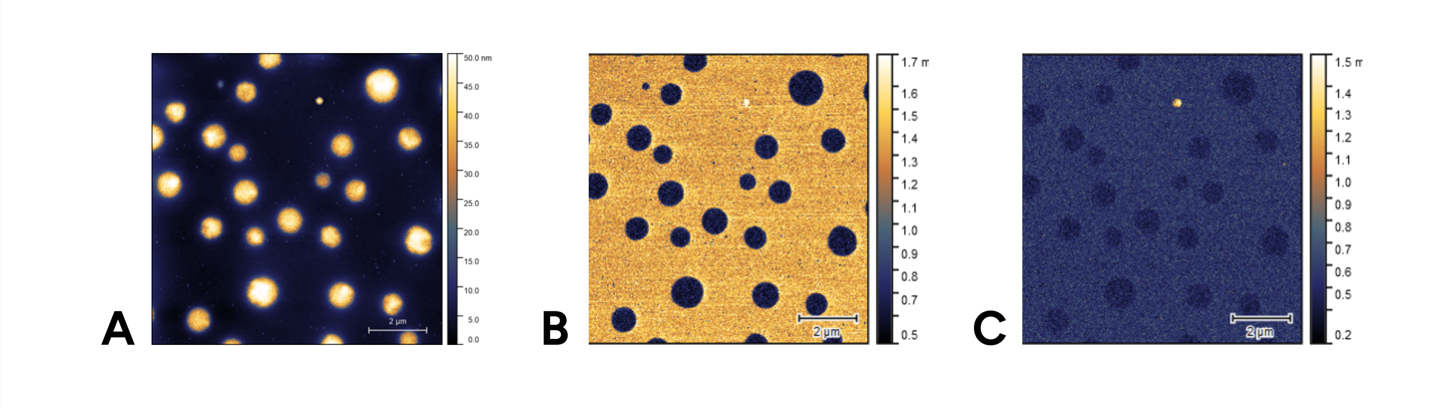

Figure 3: (A) Topography, (B) and (C) PiFM images at 1491 cm^{-1} and 1150 cm^{-1}, respectively of a PS-LDPE polymer blend sample

If you scan the wavelength at one spot, PiFM gives a spectrum:

"Absorption strength vs wavelength (a chemical fingerprint curve)"

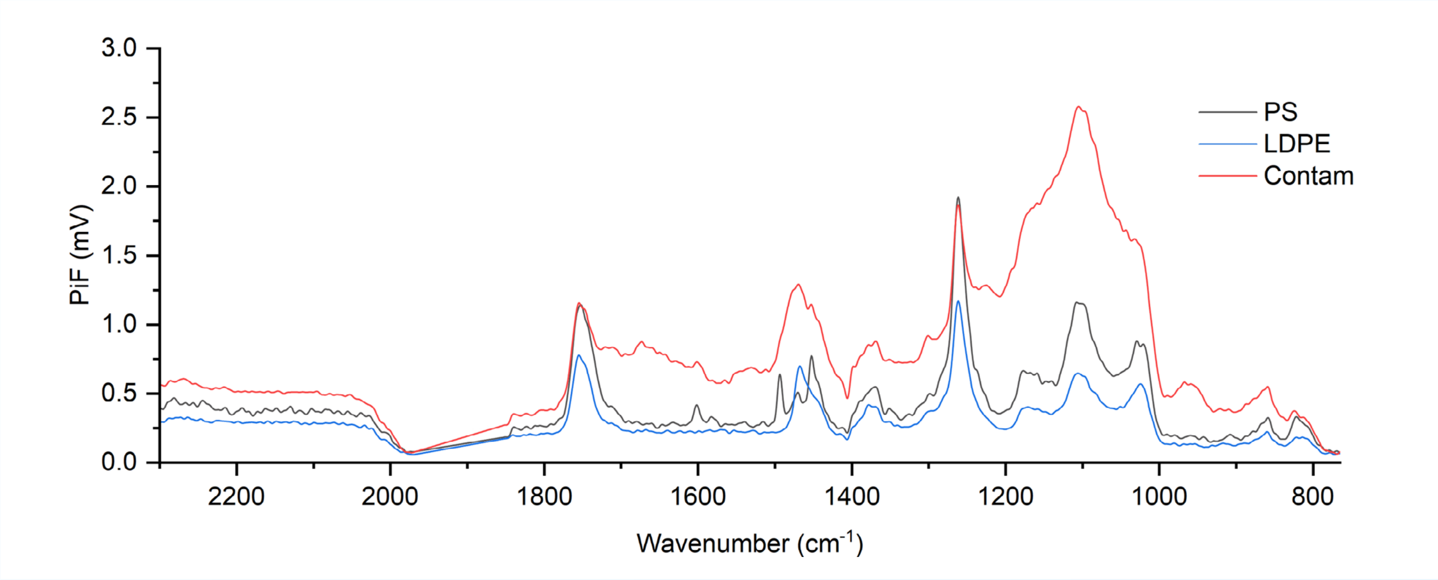

Figure 4: Shows 3 PiF-IR spectra corresponding to 3 locations on the sample surface: (Gray) PS background, (blue) LDPE domain, and (red) particle contaminant

Why PiFM is especially strong for "should-be-clean" surfaces (Surface vs bulk modes)

For photomasks, PiFM is an especially valuable technique because of the different modes that can be used during operation. Surface-sensitive mode is great for detecting ultra-thin residues/films on the surface, while bulk mode can identify subsurface or buried contaminants

- **Surface (side-band) mode:** In this mode, the frequency of the incident light does not coincide with a vibrational mode of the cantilever and instead, the IR laser is modulated by the frequency difference (f_m) between the first (f_0) and second (f_1) mechanical resonances of the cantilever. This means any residual vibration present at this frequency is suppressed by lock-in detection and the dominant force recorded is dipole–dipole interaction between the tip and the molecules. The benefits of this mode are that it scales strongly with distance and probes **< 30 nm** beneath the surface, which is great for ultrathin residues/films.

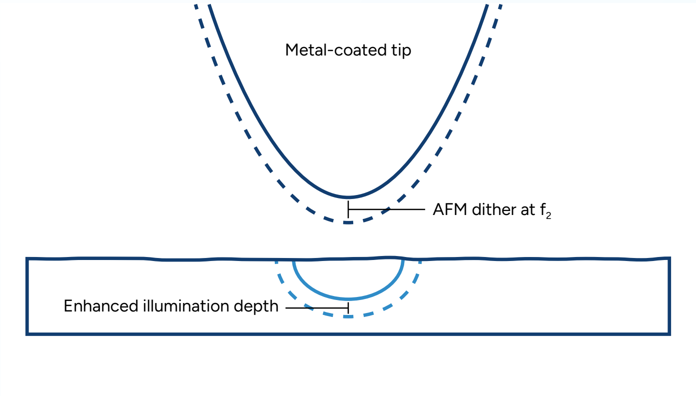

Figure 5: The enhanced illumination depth grows and shrinks as the AFM tip mechanically vibrates up and down at f_1

- **Bulk (direct drive) mode:** In this mode, the IR laser is pulsed at the fundamental frequency of the cantilever. This mode can probe **~100 nm** below surface which is useful for below-surface contamination but has more background signal contributions including photothermal gradients and far-field light scattering that compete with the near-field PiF signal.

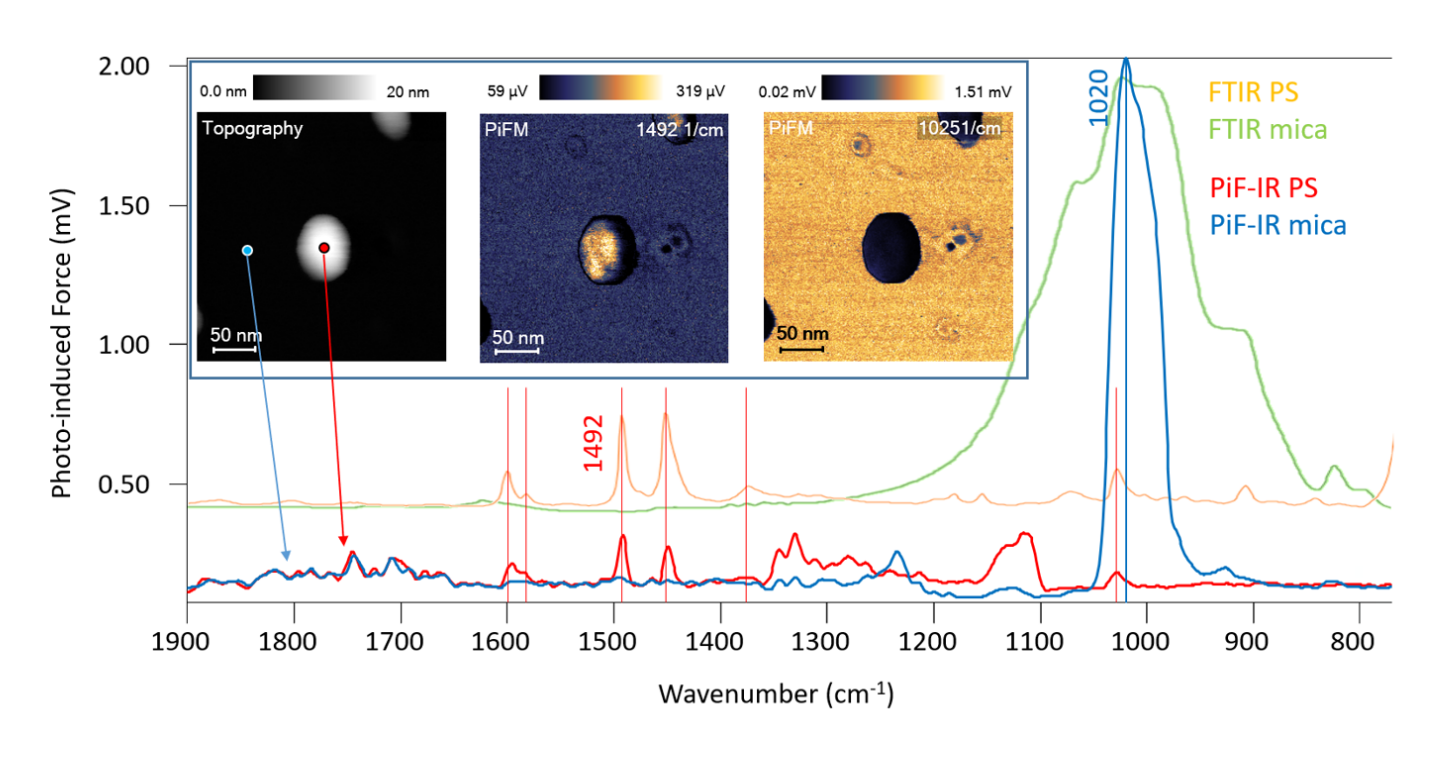

Figure 6: PiF-IR spectra acquired on a 20 nm PS nanoparticle (red) and the mica substrate (blue) along with FTIR spectra for PS (orange) and mica (green). The inset shows topography and PiFM images at 1492 cm^{-1} for PS and 1025 cm^{-1} for mica. Courtesy of Molecular Vista

Conclusion

PiFM gives photomask teams a practical new lever when "inspection found something" but the root cause is still unclear: it delivers co-registered nanoscale topography and chemical identification from the exact same location on the surface. That combination is what turns a vague defect callout into an actionable process answer—distinguishing particle vs. film, separating background from true residue, and providing PiF-IR spectral fingerprints that point toward likely sources such as resist remnants, polymer transfer, cleaning byproducts, or siloxane contamination. Just as importantly, PiFM's surface-sensitive (side-band) mode is tuned for the reality of photomasks—where the most consequential contamination can be ultrathin and confined to the top tens of nanometers—while bulk mode offers a path to investigate subsurface contributors when needed. With this capability now available at Covalent, customers can move faster from "we see a defect" to "we know what it is and where it is," enabling tighter feedback to cleaning, handling, and fab processes—and ultimately improving yield, CD control, and confidence in mask cleanliness.

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