blueDrive™ Photothermal Excitation Frequently Asked Questions

Asylum Research

Introduction

Asylum Research's **blueDrive** Photothermal Excitation option for the **Cypher S**™ and **Cypher ES**™ atomic force microscopes (AFMs) makes tapping mode techniques simpler, more stable, and more quantitative. Tapping mode is by far the dominant choice in the world of AFM, measuring not just topography, but also mechanical, electrical, and magnetic properties. Typically, piezoacoustic excitation is used to drive the cantilever oscillation. Though piezo drive is favored for design simplicity, the response of the cantilever is often far from ideal. Asylum's blueDrive excitation mechanism produces an almost perfect response by directly exciting the cantilever photothermally. This provides significant performance and ease of use benefits for all tapping mode techniques.

Remarkably simple, Strikingly accurate, Incredibly stable

1) Is blueDrive a new imaging mode?

No, blueDrive is not an imaging mode. Rather, blueDrive is an option for Asylum Research Cypher AFMs that improves all tapping mode (also known as AC mode) techniques by replacing the conventional drive mechanism with photothermal excitation. Tapping mode techniques all rely on driving the cantilever into oscillation near its resonance. Most often, a small piezo somewhere near the probe provides the drive energy, a method known as piezoacoustic excitation. blueDrive instead uses a blue laser focused on the base of the cantilever. The power of the laser is modulated,

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causing small, localized heating of the cantilever, which causes it to bend and oscillate at the modulation frequency. This method, known as photothermal excitation, produces a very clean and stable cantilever response because the cantilever is driven directly. This provides significant ease of use and performance benefits.

2) What are the advantages of blueDrive?

The cantilever drive response using blueDrive is much cleaner and more stable in both air and liquids than that obtained using piezoacoustic excitation. This provides several ease of use and performance benefits. First, setting up and "tuning" the cantilever is very simple. Traditional piezoacoustic excitation excites other mechanical resonances in the AFM that appear along with the cantilever resonance in the response. Especially in liquid, this can result in a "forest of peaks" that can make it difficult to find the correct drive frequency. Even in air though, cantilevers tunes are often distorted, ranging from asymmetric peak shapes to more severe bifurcation of the peak. Typically, these distortions are not due to some defect in the cantilever or mistake of the operator, but rather they are due to normal variability in the probe mounting that affects the drive response. The blueDrive response has no extraneous resonances to complicate the tuning process and is insensitive to variability in probe mounting. The tunes are so clean that the auto-tune feature works robustly even in liquid.

Second, the blueDrive response is incredibly stable with time and temperature variations. Once you tune the cantilever, the drive response (i.e. amplitude) remains virtually constant. This allows you to use setpoints very close to the initial ("free air") amplitude without drifting off the surface (if the response drops) or tapping at higher force (if the response increases). Using typical piezoacoustic drive, you are probably accustomed to frequently adjusting the setpoint to maintain optimal tracking. This occurs in air, but is even more pronounced in liquids. The cantilever response varies strongly with the liquid droplet volume, so the response can vary dramatically as the liquid evaporates when you use piezoacoustic excitation. Similarly, room and instrument temperature changes strongly affect the piezoacoustic response, distinct and much larger than the true resonance frequency shift of the cantilever itself. blueDrive is immune to these artifacts. If the blueDrive cantilever response changes, it's because the cantilever resonance has really changed.

Finally, blueDrive enables more quantitative results using techniques like AM-FM and Contact Resonance Viscoelastic Mapping modes. The cantilever response is very sensitive to both conservative and dissipative tip-sample interactions. These modes monitor the cantilever response and analyze it to extract information like the elastic modulus and loss modulus of the sample. Using blueDrive, the cantilever response very closely corresponds to that predicted theoretically, which reduces uncertainty in the analysis.

3) Does blueDrive heat the tip and/or sample?

We have studied tip and sample heating effects by the blue laser extensively and have found no adverse effects. Though the blue laser is capable of generating large local thermal gradients, a number of factors greatly limit heating of the tip and sample.

The blueDrive laser power is quite low, typically about 1 mW, and is adjusted lower or higher as needed for different cantilevers and drive conditions. During normal operation, the laser is aligned on the base of the cantilever (near the probe chip) and focused to a small spot. Therefore, most of the heat conducts to the probe chip, the probe mount and on to the rest of the AFM, which adds negligibly to the power it already dissipates. Very little light spills past the cantilever, even for small cantilevers, so the sample receives little incident light. Our measurements have shown that there is no measurable temperature increase at the tip itself during normal operation, as measured on typical scanning thermal microscopy cantilever.

We have carefully tested for sample heating by imaging a phase-separated lipid bilayer sample that is very sensitive to temperature and have not been able to observe any adverse effects. These observations lead us to conclude that blueDrive contributes negligible heating to the sample during normal operation.

4) Is it complicated to setup blueDrive?

No, blueDrive is not at all complicated to setup and use. The standard Cypher AFM already includes what we call the "SpotOn" feature for the IR cantilever deflection detection laser. This allows you to simply click on the video view of the cantilever and the laser spot automatically moves to that point. blueDrive works the same way, you simply click where you want the spot to be focused. One click for the IR laser, one more click for blueDrive, that's it. If you're changing the probe but replacing it with the same style, then it's even easier. The IR spot and the blueDrive spot can be moved together, reducing it to just one click. Both laser spots are visible in the video view, so you know immediately that they have been aligned correctly. All that remains is to tune the cantilever resonance. As already described, the cantilever tune is much easier with blueDrive compared to typical piezoacoustic excitation.

To be sure, blueDrive complicates the design of the AFM, but not its setup and use. blueDrive uses sophisticated optoelectronics to introduce the extra blue laser. Asylum Research is the only AFM company to offer this technology. The modular optical design of the Cypher is what makes it possible.

5) Does blueDrive require special cantilevers?

No, blueDrive does not require special cantilevers. It works best with gold-coated cantilevers, but many probes are already gold coated to enhance their reflectivity. blueDrive also works with uncoated silicon cantilevers. This allows blueDrive to readily operate with a wide range of probes with spring constants ranging from <0.01 N/m to >40 N/m and with both conventionally sized cantilevers and smaller, fast cantilevers.

Only aluminum coated probes are not recommended for use with blueDrive. Typically such probes are also available either uncoated or gold coated.

6) How is blueDrive different from iDrive and other magnetically actuated AC modes?

Several companies, including Asylum Research, have introduced magnetic actuation options for tapping mode. Asylum calls this "iDrive", which works by passing an alternating current through the legs of a v-shaped cantilever in a magnetic field, creating an oscillating magnetic force that drives the cantilever. Other companies have used a second approach in which special cantilevers with a magnetic coating are driven with an external magnetic field generated by a nearby coil. This approach can generate significant heating and subsequent drift due to the relatively high power dissipation of the drive coil. In practice, the drive response of this approach is not as clean as one would expect, perhaps due to coupling with other nearby magnetic components. Both approaches to magnetic actuation require special cantilevers, available in limited spring constants and at higher cost than standard probes. Magnetic actuation has also been used almost exclusively for imaging in liquid and is not practical for smaller, fast scanning cantilevers.

blueDrive, in contrast, can operate in both air and liquids. It can use a wide range of different standard probes and is also compatible with small, fast scanning probes. These differences make blueDrive much more versatile and capable.

7) Is blueDrive different from typical tapping mode?

Again, blueDrive is not a new imaging mode, rather it is a new drive mechanism that improves the ease of use and performance of the full range of tapping mode techniques.

8) What tapping mode techniques are compatible with blueDrive?

blueDrive works with all tapping mode techniques that are supported on Cypher AFMs. These include conventional topographic imaging with tapping mode, phase imaging, magnetic force microscopy (MFM), electric force microscopy (EFM), Kelvin probe force microscope (KPFM, or SKPM, or surface potential imaging), loss tangent imaging, and AM-FM Viscoelastic Mapping mode. blueDrive is also compatible with all Asylum-supported feedback modes, including the conventional AM mode (amplitude feedback), FM mode (frequency feedback), and exclusive modes like Dual AC Resonance Tracking (DART). It can also be used to actuate the cantilever in Contact Resonance Viscoelastic Mapping mode, which may not normally be considered a tapping mode technique, but still uses cantilever actuation.

9) Is blueDrive affected by ambient temperature changes or sample heating and cooling?

No, blueDrive is almost entirely immune to drift in the cantilever response due to both unintentional room temperature changes and even intentional sample heating and cooling. The thermomechanical actuation process is highly localized at the base of the cantilever, so the surrounding environment has very little impact on the response.

10) Does blueDrive work in liquid?

Yes, absolutely. Some of the benefits of blueDrive are especially relevant in liquids. It's also worth noting that blueDrive works in a wide range of liquids, not just water. Very viscous liquids have typically been problematic for tapping mode using piezoacoustic excitation, but blueDrive can drive cantilevers even in very viscous fluids like ionic liquids.

11) Are there any advantages of blueDrive specific to imaging in liquid?

There are a few advantages to blueDrive that are especially pronounced when operating in liquids. First, tuning the cantilever resonance is much simpler. You will see a single, clean peak at the resonance. You can even use the auto-tune feature if you like. If you look at higher frequencies you might also find resonances of the higher modes and harmonics of the resonances. These of course are part of the real cantilever response, but they don't cause any trouble or confusion because they are smaller than the first resonance and far separated in frequency. More importantly, what you won't see is the "forest of peaks" that piezoacoustic excitation produces in liquid. Even so-called "direct drive" piezo-driven cantilever holders produce a very messy, complicated cantilever response in liquid. A common workaround is to first measure the thermal response. This does find the true cantilever resonance, however the piezoacoustic drive response may have many peaks under the broad thermal resonance peak. Unfortunately not all of them work or work well, so there can be a lot of trial and error to find the best response. Sometimes there is simply not much of a response at all near the resonance.

The other peculiarity of piezoacoustic drive in liquid is that the response can vary strongly depending how far the cantilever is above the surface. When you tune the cantilever above the surface and then begin to engage, the amplitude often begins to change long before the cantilever is actually near the sample. Once engaged, if you retune near the surface the response often looks very different, with some peaks having disappeared, new ones having appeared, and other having changed in amplitude. This is a result of the complicated piezoacoustic drive mechanism, where resonances of the probe holder, the whole AFM and even the fluid itself contribute to the measured response. You don't see this effect with blueDrive. The amplitude stays very stable as the cantilever approaches the sample because it's being driven directly. Only when the tip begins to interact with the sample do you observe a change in the amplitude. This makes it easier to achieve stable, gentle imaging conditions.

The blueDrive response is also not affected by the liquid volume. If some liquid evaporates during imaging it does not change the response or the imaging stability as long as liquid remains around the cantilever. This is not true for piezoacoustic excitation. As liquid evaporates, the resonances of the fluid volume itself change, and this affects the measured response. This is part of the reason why tapping mode in liquid never seems to be as stable as tapping mode in air. But with blueDrive, this issue is eliminated.

Together, these benefits of blueDrive in liquid begin to make the tapping mode imaging experience in liquid much more like what you expect in air – simple and stable.

12) Is blueDrive fast?

blueDrive is not a specific imaging mode, but rather is a new drive mechanism general to all tapping mode techniques. However, blueDrive enables reliable use of small cantilevers known to offer low noise and fast scanning capabilities. Small cantilevers present more challenges to drive cleanly and effectively with piezoacoustic excitation. blueDrive is proven to at least 8 MHz drive frequency and the cantilever response is just as clean and perfect at MHz frequencies as it is at kHz frequencies.

13) Is blueDrive useful in air?

Yes, all of the benefits already discussed are also relevant to operation in air. When using piezoacoustic excitation, the higher quality factor (Q) of the resonance in air tends to make the tunes look nicer than in liquid because the resonance peak is narrow and taller. But the same sort of distortions are still present and can affect ease of use, stability, and quantitative interpretation of the resonance.

14) Are there any disadvantages to blueDrive?

No, there really are no disadvantages to blueDrive. As already discussed, despite the more advanced technology blueDrive is simpler to use than piezoacoustic excitation. From a performance standpoint, there are only improvements relative to piezoacoustic excitation, some of which are especially dramatic in liquid.

One small limitation is that gold coated probes work best to achieve high amplitudes and aluminum coated probes are not compatible. Virtually all probes commonly used for imaging in liquid have standard gold coating. Stiffer probes for tapping mode imaging in air are less commonly available with gold coating, though most are available uncoated.

15) How do I align the blue laser?

It's easy and described here.

16) Is it possible to use blueDrive on the MFP-3D?

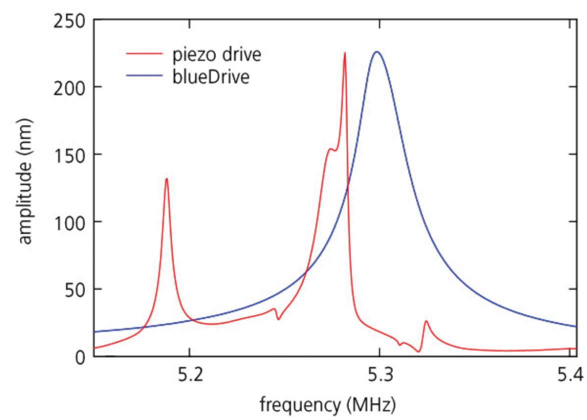
No, blueDrive is an option exclusively available for the Cypher S and ES AFMs. The Cypher AFM was designed with an optical infinity space (where the laser light and camera light are collimated) making the introduction of additional laser light (such as blueDrive) relatively easy. Other AFMs, including the MFP3D, do not have such modular optics that allow easy introduction of additional laser light. Adding additional lights would require significant hardware changes and compromise other functionalities of the AFM.

17) What amplitudes can you drive with?

Every cantilever is different. Some cantilevers have a very large photothermal response, while others have a smaller one. For gold coated cantilevers, the ranges we have been observing are between several tens of nanometers to several microns.

18) What frequency can you drive the cantilever with?

We can drive cantilevers >10 MHz, but because our optical beam deflection system rolls off at 8 MHz, we do not guarantee anything above 8 MHz. The following graph shows a USC-EBD cantilever driven at ~5 MHz with an amplitude of >200 nm.



19) Is there a particular reason why 405nm was chosen as the wavelength for the blueDrive laser?

There are a few practical reasons. First, 405 nm light is absorbed well by gold, which makes the photothermal response more efficient. Our standard deflection laser is in the infrared, which happens to be well reflected by gold. This is the ideal situation, where the photothermal laser is strongly absorbed and the deflection laser is strongly reflected. The choice of 405nm is also convenient to maintain a high quality optical view of the tip and sample. Both the 405 nm laser and the IR deflection laser would saturate the camera if they were not filtered. Having the two wavelengths at opposite ends of the visible spectrum allows us to use a simple bandpass filter that reduces the intensity of the laser light while maintain good color balance. Finally, by staying within the visible spectrum we can use conventional optics and avoid problems with transmissibility and aberrations that occur at longer and shorter wavelengths.

20) Can the blue laser spot be moved accurately in precise steps along the cantilever?

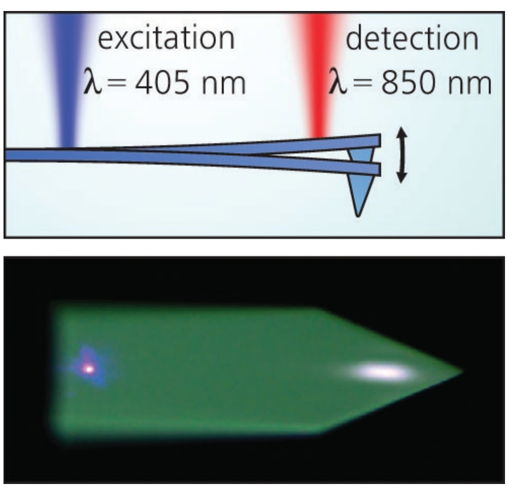
Normally the blue laser spot is moved by clicking on arrow buttons in the software interface. This allows precise, sub-micron positioning of the spot position, which can be monitored in the optical view.

For special purposes requiring more precise positioning, the laser position can also be moved programmatically with a step size precision of 25 nm. This would allow, for instance, to step along the cantilever and collect tunes of the cantilever response at precise points along its length.

21) For positioning the blue laser, is there a preferred location on the probe?

Fortunately, in the vast majority of cases the optimal location is very simple and consistent. As described above, you should generally align the blue laser at the base of the cantilever along the centerline of the cantilever. This minimizes heating of the tip and maximizes the amplitude response. This same position can be used to excite not only the first resonance but also higher modes, if desired.

More generally, there is a dependence on location and this can be readily mapped. Though not necessary for typical use, it offers interesting possibilities. For instance, at some locations the response for a given mode may be strong while the response for another mode is minimized.



22) Why do you recommend shining the blue light at the base of the lever?

The photothermal effect relies on locally heating the cantilever, and inducing curvature because the top side of the cantilever expands more than the (colder) bottom side of the cantilever. This effect is enhanced if there is a coating on the cantilever which expands when heated. Because the shape of a cantilever vibrating on resonance has the most amount of curvature near its base, the most efficient location for the blue light spot is at the cantilever base.

23) What role does photonic pressure play in driving the cantilever oscillation?

The photothermal effect (thermally induced local bending of the cantilever) dominates the photonic pressure contribution on all the cantilevers that we have tested. On gold coated cantilevers, the photothermal effect dominates by orders of magnitude.

The qualitative difference between photothermal vs photonic pressure induced cantilever bending is the dependence of the blue light location. The photothermal effect is strongest when the blue spot is at the base of the lever, while the photon pressure is highest at the tip of the lever. In any case, we recommend shining the blue light at the base of the lever where the photothermal effect largely dominates the photonic pressure, if any.

24) Why can't you excite the cantilever below 1 kHz and above 8 MHz?

For coated cantilevers , the photothermal response is actually highest at low frequencies. Therefore, it is possible to excite cantilevers photothermally all the way down to 0 Hz, in principle. The 1 kHz lower cutoff was an engineering choice made in order to allow us to measure the DC power of the blue light with several 100 Hz bandwidth in order to quickly adjust the blueDrive power on startup and to provide a measure to keep the blue light DC power stable. It is technically possible to operate blueDrive below 1 kHz, but this is not supported by our standard software package.

We can very efficiently drive cantilevers up to 8 MHz in resonance frequency, and expect that cantilevers can be driven at much higher frequencies. However, the photodetector that measures the cantilever oscillation rolls off around 8 MHz, and therefore we cannot use cantilevers at drive frequencies well above 8 MHz.

25) Is blueDrive a standard feature on the Cypher, or is it an option?

blueDrive is an option on any of the Cypher AFMs. Existing Cyphers in the field can also be retrofit for blueDrive compatibility.

26) Is blueDrive compatible with the high voltage Cypher and Cypher ES?

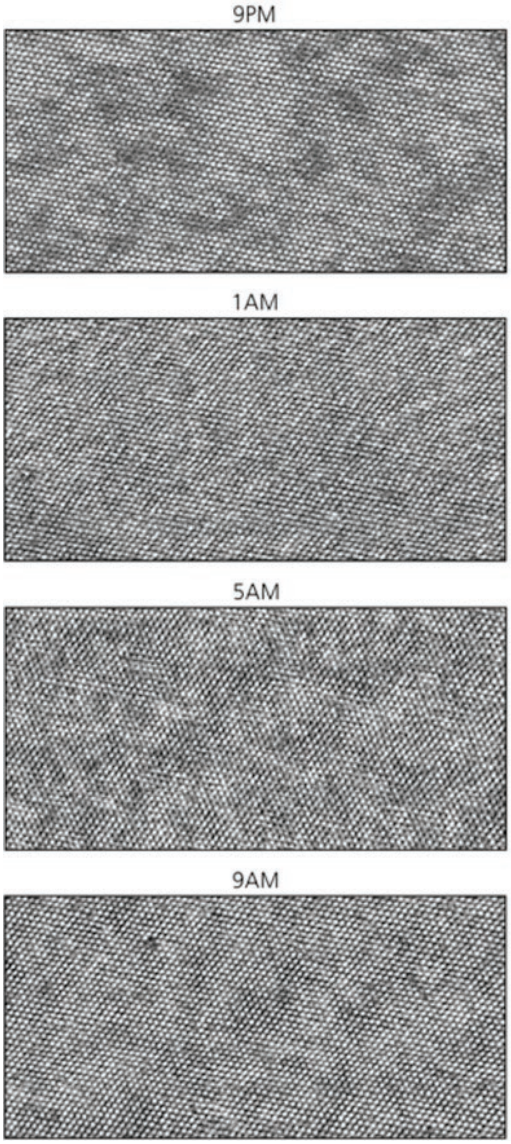
Yes, blueDrive is compatible with all variations of the Cypher AFM. This is because the blue light is focused onto the cantilever through the same objective lens as the detection laser. Therefore, blueDrive does not interfere with any of Cypher's existing hardware and accessories.

27) Can you use v-shaped cantilevers with blueDrive?

Yes. Although we typically don't select v-shaped cantilevers for imaging with blueDrive, we have acquired very nice images with triangular cantilevers driven by blueDrive without any complications. The blue light should be focused near the base of either of the arms of the cantilever.

28) Do cantilevers require more frequent replacement with blueDrive relative to piezo drive?

No. In fact, tips remain sharper with blueDrive because this drive mechanism is more stable than piezo drive, especially in liquids. This avoids tip damage because it allows more control over the imaging forces and the amplitude setpoint remains steady. As an example, the figure below shows a mica overnight scan where the stability of blueDrive in liquids allowed the Cypher to image atomic resolution images for 12 hours without human intervention. Note the atomic point in the last image, which attests to the atomically sharp tip after 12 hours of imaging.



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