

Superior Pointing Stability Simplifies MPE Imaging

A clever optical design, superior component tolerance, rugged engineering, and rigorous factory testing ensure the pointing stability of the Chameleon™ Vision is virtually twice as good as any other dispersion compensated MPE laser source, avoiding any need for tweaking the alignment between the laser and MPE microscope.

Introduction and Overview

Multiphoton excitation (MPE) applications have become demonstrably easier since one-box ultrafast lasers made available an ideal combination of optimized performance and operational simplicity. And because MPE microscopes are often shared resources, users also derive considerable benefit from the wide tuning range of these hands-free lasers – 680 nm to 1080 nm in the case of the Coherent Chameleon series. For instance, the long wavelength is particularly useful for optimum excitation of red fluorophores such as m-cherry. And more recently, the integration of smoothly and widely variable group velocity dispersion (GVD) compensation of up to 47,000 fs² – enables the final, at-sample, pulsewidth to be varied and/or minimized at will, even for next generation microscopes with multiple AO modulators. Although all this useful functionality is now provided with push-button simplicity, it's very important that its implementation does not compromise beam pointing stability, either during normal use or when a laser is moved. That's because beam pointing stability is critical to maintaining downstream alignment between the laser and the microscope. Without adequate pointing stability, changes in the laser output parameters could necessitate re-alignment of the beam into the microscope, negating the very simplicity and experimental efficiency these lasers were originally devised to provide. In this whitepaper we detail the design and construction factors which lead to superior alignment for the Chameleon Vision.

Microscope Alignment

In a MPE microscope, the input alignment is very important. The most critical alignment is with the back aperture of the objective. Ideally, the beam is centered on this aperture and overfills it so that the laser beam is

close to a plane wave. Any misalignment manifests primarily as lost intensity at the sample. However, since the beam intentionally overfills this aperture, some beam walk-off can be tolerated. How much? The exact specifics depend on the particular microscope model, but as a rule of thumb, a laser pointing deviation of 400 microrad is a typical maximum value that a MPE microscope can tolerate before the at-sample intensity drops noticeably. If the deviation is higher than this then the operator will have to tweak the steering mirrors between the laser and microscope, which is a very undesirable scenario for a high-throughput resource often shared by several scientists who may not all be experts in optical alignment.

Defining Performance

In a well-designed integrated oscillator, the primary source of potential pointing deviation is wavelength tuning, since the refractive indices of the cavity optics vary with wavelength. So the critical specification is beam pointing as a function of output wavelength. The Chameleon Vision has a specified pointing stability of 80 microrad per 100 nanometers of tuning.

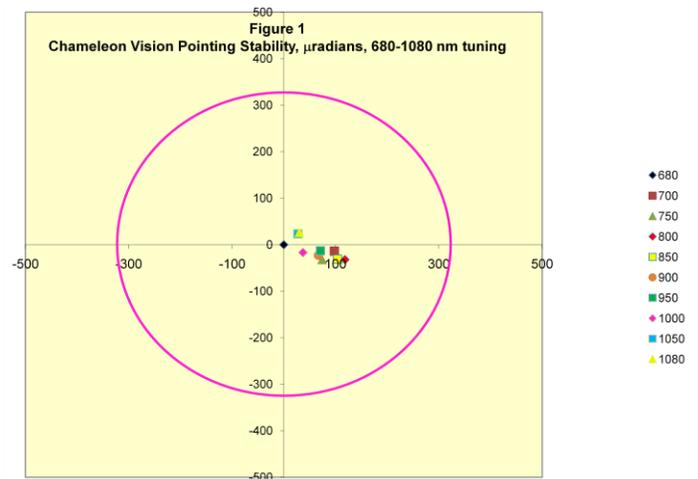


Figure 1: The Chameleon Vision has a specified pointing stability of 80 microrad per 100 nanometers of tuning. As shown by this test data, the typical performance is normally far better than this guaranteed worst-case specification.

That means that even for 400 nm tuning, the maximum pointing movement is only 320 microrad, which is well below the 400 microrad threshold where intensity effects can be noticed in typical microscopes. Moreover, the typical performance is normally far better than this guaranteed worst-case specification, as shown in Figure 1.

Indeed, the Chameleon Vision currently has the best pointing stability specification for any dispersion compensated MPE laser. But when comparing MPE lasers, it is very important to understand how the pointing is being specified. The microscope input aperture has a circular cross section, so at Coherent, we use a radial specification, i.e. 80 $\mu\text{rad}/100\text{ nm}$ in any axis. That's because with a circular aperture, it doesn't matter which direction the beam walks – if it's more than 400 microrad, it can be a problem. However, some MPE lasers are specified according to performance in orthogonal axes, which is somewhat different. For example, a laser specification of 100 $\mu\text{rad}/100\text{ nm}$ in each (xy) axis is not the same as a radial specification of 100 $\mu\text{rad}/100\text{ nm}$. To understand this, consider a worst-case scenario for both specifications. 80 $\mu\text{rad}/100\text{ nm}$ in any axis means just that – this is the maximum beam deviation any axis, i.e. 320 μrad for 400 nm tuning. But for a specification of 100 $\mu\text{rad}/100\text{ nm}$ in each (xy) axis, the maximum deviation is 100 μrad in the x axis and 100 μrad in the y axis, giving a maximum radial deviation of $\sqrt{20,000}$, i.e. 141 μrad (see Figure 2). So what appears to be only a 20% difference in specification is actually almost a factor of 2, with a worst case scenario of 565 μrad for 400 nm of tuning.

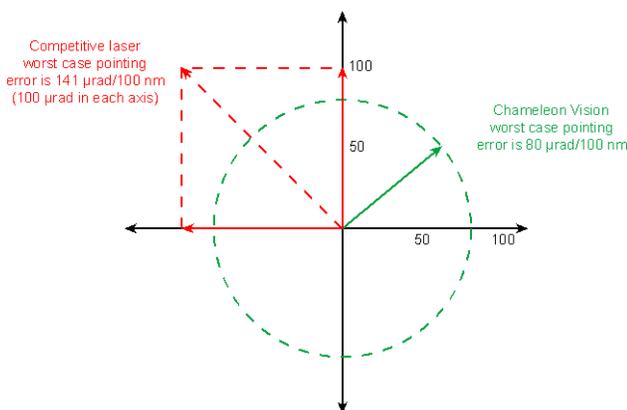


Figure 2: The Chameleon Vision delivers a specified pointing stability better than 80 $\mu\text{rad}/100\text{ nm}$ in any axis. For comparison, we show a specified pointing stability of 100 $\mu\text{rad}/100\text{ nm}$ in x and y axes, where the worst case beam deviation is actually 141 $\mu\text{rad}/100\text{ nm}$.

Stability by Design

How does the Chameleon Vision deliver this superior performance? The key is in the design and assembly as well as rigorous testing. This laser is inherently very stable in terms of beam pointing, which is preferable to the alternative of inferior performance and active compensation. The latter would add unnecessary cost and complexity.

One way to achieve passive stability in an optical system with an adjustment involving angular rotation is to use a retroreflector. These are prisms or mounted mirror assemblies that return an incident light beam back along an axis that is perfectly parallel to the incoming light path. Where the beam is large enough to fill the input aperture of a retroreflector, the return beam retraces the path of the incident beam.

Obviously, system performance depends on manufacturing the retroreflector(s) to extremely high angular tolerances. Extensive testing and evaluation in Coherent's R&D laboratories has shown that the best solution for an MPE laser is to use a different type of retroreflector, the rooftop or Amici prism (see Figure 3). These are right angle (90°) prisms that provide a retroreflection parallel in one plane only. Using two of these prisms allows any slight walk-off in both x and y axes to be avoided, yet without specifying trihedral prisms or hollow retroreflectors optics with tolerances that would be very difficult (and prohibitively expensive) to consistently produce. Nonetheless even using rooftop prisms requires custom optics, designed and fabricated at Coherent – no commercial catalog prisms offer the necessary tolerance.

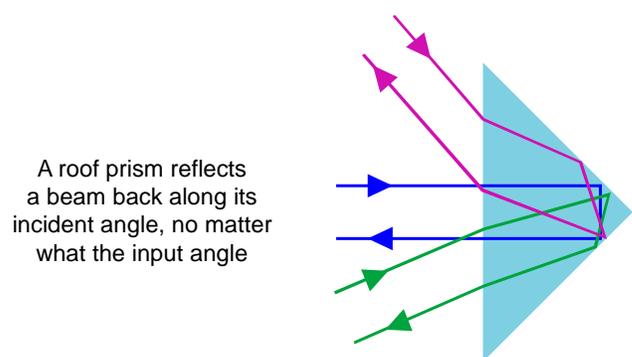


Figure 3: When used as a retroreflector, a rooftop prism returns an incident beam back along its original direction. This automatically corrects for any angular walk-off due to rotation of optical elements in the beam path.

Of course, opto-mechanical stability is also important, particularly in a compact one-box laser intended to be easily moved from bench to bench or even lab to lab. Again, Coherent has opted for inherent passive stability over complex and costly active correction. This includes extensive use of our patented PermAlign™ mounting method for critical optics, all the way through the system – from the green Verdi™ pump laser to the final GVD pre-compensation module as well as between the Ti:Sapphire oscillator output and this module. With PermAlign, each optic is precisely aligned and then soldered into a one-piece mount which is rigidly bolted to the laser baseplate. With no adjustment screws, there is no possibility of such a mount being shifted out of alignment by thermal variations or by mechanical vibration or shock. This is the reason that Chameleon Vision can be moved around an optical table or transported from one lab to another without any degradation in the alignment between the Ti:Sapphire oscillator and the GVD module. With competitive designs using conventional multi-part mounts, this is frequently not the case.

The final element enabling Chameleon's superior specifications is comprehensive testing. As famously demonstrated by the initial problems with the Hubble telescope, this requires full testing of the entire system operating in its intended mode.

With every single Chameleon Vision we build, we want to find any stability problems so that you don't. This includes environmental testing and cycling of each laser before shipping, under conditions that truly represent conditions beyond the worst case the laser can be expected to have to endure during its lifetime. Where necessary, Coherent engineers analyze and identify the root cause and correct it. Key aspects include temperature, humidity and vibration cycling – often referred to by quality engineers as “shake and bake.” The laser output is continuously monitored during these tests to check that its performance never deviates beyond guaranteed specifications.

Conclusion

The Chameleon Vision is a high-performance laser source for many types of MPE microscopy, providing a superior wavelength tuning range as well as the highest amount of adjustable GVD compensation. And due to its unrivalled beam stability characteristics, it's also a high-throughput source designed to ensure you're time is spent taking images and other data, and not spent tweaking the alignment as imaging conditions change.