Dichroic Mirror characterization with MESO™

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APPLICATION NOTE

Summary

A dichroic mirror has the property of transmitting a defined range of wavelengths and reflecting the other. A shortpass dichroic mirror (DM) transmits wavelengths lower than a cut-off wavelength and reflects wavelengths higher than the same cut-off. When this type of optics is in use inside an optical system that demands high quality wavefront, a transmission and a reflection wavefront analysis might be necessary.

In this application note, a characterization of a dichroic mirror will be done using Imagine Optic's metrology system MESO™. With MESO™, it is possible to characterize any type of flat optics at multiple wavelengths, as it is achromatic and can embed up to three sources. Consequently, for the production or use of dichroic mirrors for a wide range of cut-off wavelengths, it is possible to perform transmission and reflection measurements at different wavelengths in minutes.

I. Method

Presented here are a series of measurements of the shortpass dichroic mirror DMSP1000 from Thorlabs (∅50.8 mm). A high-quality transmitted wavefront with PV error smaller than λ/4 @633 nm over clear aperture is guaranteed by the manufacturer, but there is no specification for surface flatness or reflection wavefront.

Figure 1: Photo of the dichroic mirror used.

The DMSP1000 is specified for 45° angle of incidence (AOI) and has a cut-off wavelength at 1000 nm. Its transmission and reflectance plots can be seen below:

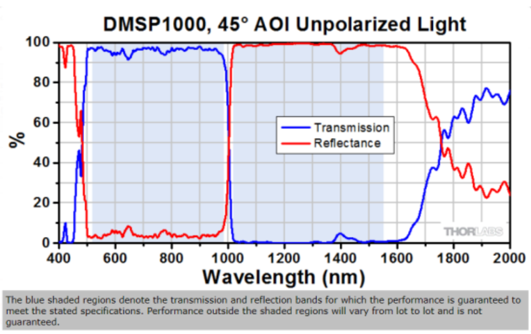

Figure 2: *Transmission and reflectance graphs for the DM [1].*

II. Transmission at 635 nm

Firstly, the transmission wavefront measurements were taken at 635 nm for 0° and 45° AOI (set-ups Figure 3).

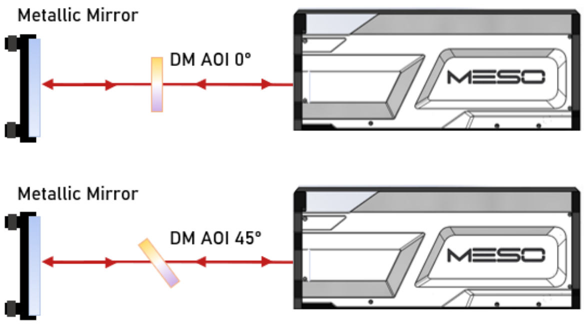

Figure 3: *Transmission measurements set-ups.*

The results were acquired and processed by Imagine Optic's proprietary software WaveSurf, and a mask was used to perform the analysis on the clear aperture specified by Thorlabs, ∅45.72 mm (Figures 4 and 5). It is clear that the optics respects very well the quality advertised by the manufacturer for 0° and 45° AOI, with a PV of 0.235λ 45° AOI.

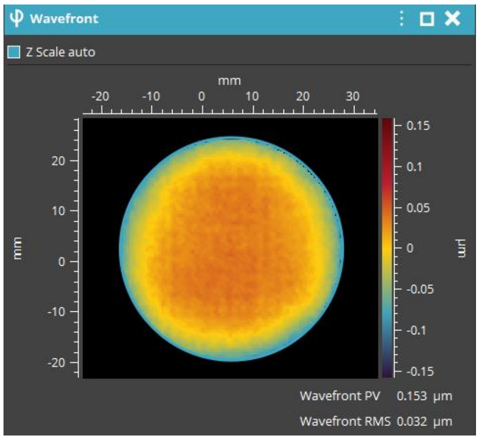

Figure 4: Transmission wavefront for 0° AOI at 635 nm (radius of curvature measured is -1531.0956 m)

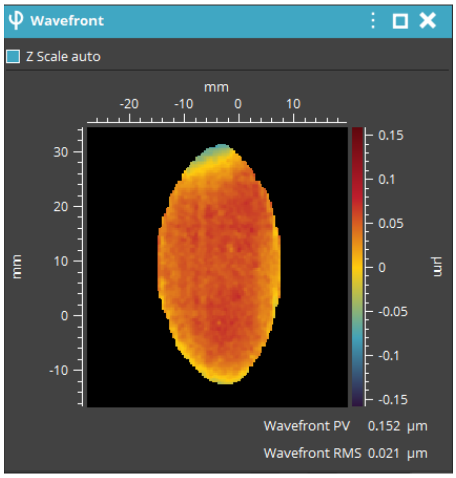

Figure 5: Transmission wavefront at 635 nm for 45° AOI. Due to the angle of incidence and the mount, the wavefront has an elliptic form.

The measurements on the two angles are consistent and show that the optics has the expected quality in transmission, independent of the angle of incidence.

But dichroic mirrors are also reflecting incident light and wavefront quality is a matter of importance depending on the application (see section IV.).

III. Reflection at 1064 nm

Therefore, we will now evaluate reflected wavefront quality of our shortpass dichroic at 0° and 45° AOI at 1064 nm (set-up Figure 6). The same MESO™ was used, as it is calibrated to be used at multiple wavelengths with the costumer's chosen embedded sources. **While an interferometer usually can only work at one wavelength, MESO™ can take at wavelength measurements according to the specifications of user's optics.**

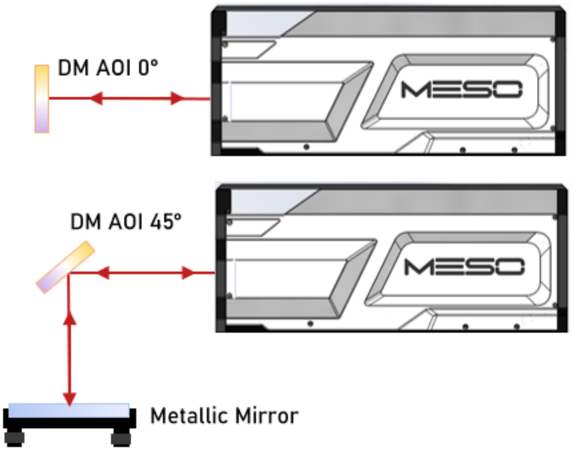

Figure 6: Reflection measurement set-ups.

The results are shown in Figures 7 and 8:

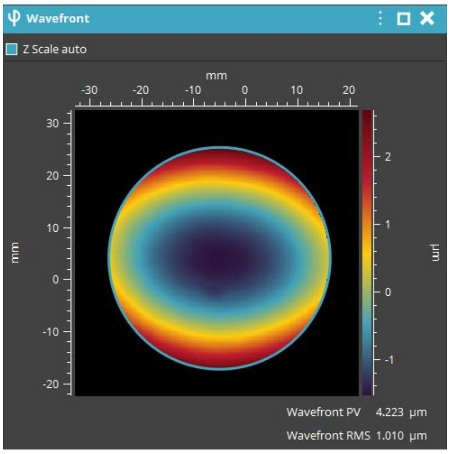

Figure 7: Surface Figure Error (sfe) for 0° AOI at 1064nm (radius of curvature measured is -70.3749 m).

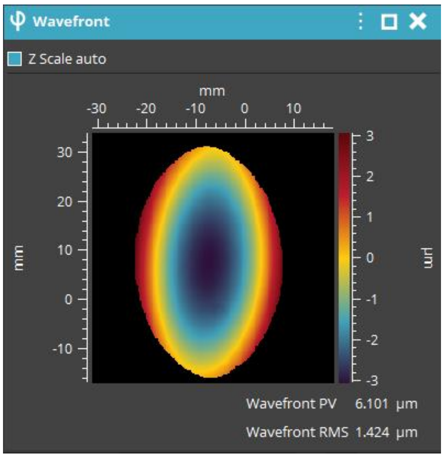

Figure 8: Surface Figure Error (sfe) for 45° AOI at 1064nm.

Because of the 45° angle and the mount, the projected wavefront in Figure 8 is not measured on the full clear aperture, but at ∅42.44 mm (83.5% of the full aperture). Consequently, the 0° wavefront was also analyzed with this same aperture so that results can be compared.
In addition, to compare both measurements, it is necessary to account for the projection effect at 45° in such way that:

0° AOI phase error = 45° AOI phase error × cos(45°)

The results after correction are:

	0° AOI	45° AOI (corrected)
sfe PV	4.233 µm	4.314 µm
sfe RMS	1.010 µm	1.007 µm

Both measurements are in agreement. We can see that the wavefront PV is more than 28 times bigger than in transmission.

Furthermore, the defocus estimated by WaveSurf for the Thorlabs clear aperture is 1.0357 µm, more than 45 times bigger than what was seen in the transmission wavefront. If the mirror is turned around and another reflection measurement is taken, the defocus observed is -1.0973 µm. We see here that we are dealing with two (almost parallel) curved surfaces with curvatures that compensate each other in transmission. This compensation, however, does not guarantee wavefront quality and flatness in reflection.

Both measurements show that, for an imaging system, the quality in reflection of the dichroic mirror might be insufficient.

IV. Application examples

Many examples of dichroic mirrors being used in reflection can be found in the literature. For instance, in the imaging system in Figure 9 (S. Carney et al. [2]), which aims to compare two Quantitative Phase Imaging (QPI) methods, a shortpass dichroic mirror DM (Thorlabs DMSP550) is used to separate one beam in two. The 4f optical system before the DM has a 150 mm focal length. Both the transmitted beam and reflected one enter two different cameras that take the measurements simultaneously in order to compare digital holographic microscopy (DHM) and transport of intensity equation (TIE) imaging.

In this case, if there was a big difference in quality between the reflected and the transmitted wavefront, the cameras performing the TIE imaging and the DHM imaging would be illuminated by lights of completely disparate quality. This would worsen the accuracy of the comparison. Consequently, when dealing with dichroic mirrors, it is important to understand the quality demanded by the application and if the optics will be used in reflection or in transmission.

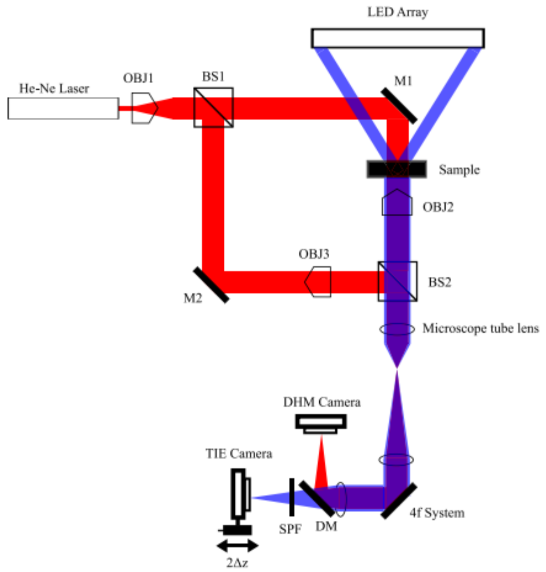

Figure 9: Example of shortpass dichroic mirror use. Schema for comparing Quantitative Phase Imaging methods. [2]

There are other applications that use longpass dichroic mirrors, such as multi-color (multi-wavelength, i.e., spectral) fluorescence detection, an indispensable method for biomedical analyses [3], TIRF (Total Internal Reflection Fluorescence) microscopy [4], Confocal Laser Scanning Microscopy [5] and Raman spectroscopy [6]. The cited applications of these methods rely on the imaging of a reflected beam from one or more dichroic mirrors.

References [3], [4] and [6] make use of multiple dichroic mirrors to separate light from 3 or more different wavelengths. When there is no specification corresponding to surface quality of the optics, each DM can have very different curvatures for each surface that later compensate each other in transmission. Consequently, in reflection, besides the possible introduction of high aberration in the imaging system, those aberrations might be completely different for each dichroic mirror used.

There are dichroic mirrors with specified surface flatness in the market, and those should be ideal for an application where the reflected wavefront is used. In the review article [7], Filters and mirrors for laser applications, a surface flatness of less than 1/2 wave per inch before coating is suggested for demanding laser applications, such as Raman Spectroscopy.

Conclusion

Therefore, to achieve high optical quality, low aberration systems, a wavefront analysis may be required.
With an equipment such as the MESO™, it is possible to easily take measurements at multiple wavelengths according to your sample specifications.
If your dichroic mirror cut-off wavelength is in the VIS-NIR, it can be characterized either in transmission and in reflection using MESO™.

References

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