APPLICATION NOTE

M² measurement with CAM SQUARED

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Summary

One way to characterize a laser beam is to compute the beam quality factor called M² or M-squared. This factor is used to compare the divergence and the waist size of a beam to a Gaussian one. It is equal to one in the case of a perfect TEM00 gaussian beam and its value increases when the tested laser quality decreases (it won't be possible to focus or collimate it perfectly).

This measurement is defined by the standard ISO 11146: the measurement of 10 different frames is required to get the M² value. However, Imagine Optic developed a variation to access to this value which needs one single measurement to generate the 10 frames. This approach is based enabled by CAM SQUARED sensor, used together with the Application 'M2' based on the WAVEVIEW 4.3.2 metrology software.

This application note first introduces the new M² factor acquisition method developed by Imagine Optic. It then presents the results obtained with CAM SQUARED by laser manufacturers on three different sources.

I. M² computation: how does Imagine Optic challenge the status quo?

The M² factor is defined by the international standard ISO 11146 as:

$$M^2 = \frac{\pi w_0 \theta}{\lambda}$$

Where Θ is the beam divergence, w_0 is the beam waist and λ is the wavelength (cf. Figure 1).

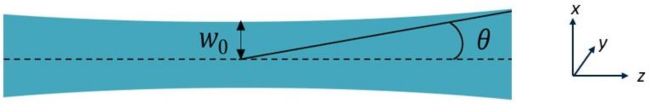


Figure 1: Beam parameters used to compute the M²

M² is greater or equal to 1. Unity means the laser presents a perfect Gaussian beam and can be perfectly collimated (if divergent) or focused (if collimated) as in Fig. 2 below.

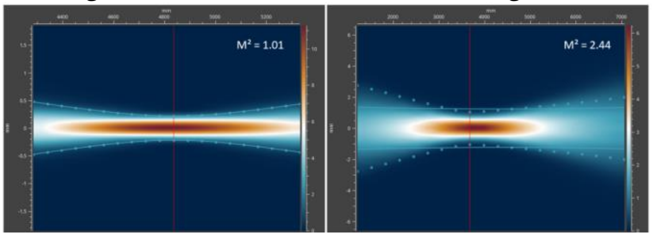


Figure 2: Example of a beam with a M² = 1.01 (left) and a beam with a M² = 2.44 (right)

<u>M² acquisition according to the Standard ISO 11146:</u>
The Standard ISO 11146 requires at least 10 measurements: the beam is measured at 10 different observation planes using a camera moving among the z axis. Then, each of the 10 images is analyzed to compute laser characteristics.

<u>Classic M² measurement:</u>
Usually, measuring the M² requires a camera mounted on a translation stage or a graduated rail so the camera can be moved to the 10 different positions. This method can be time consuming and can be affected by any perturbation during the measurement (vibrations, ambient light…). It also requires to choose a lens focusing the beam within the travel range so that acquisition points can be taken at different position away from the waist.

<u>Imagine Optic's solution:</u>
Based on feedback from its customer in the laser manufacturing industry, Imagine Optic has developed another method to measure the M² which consists in using the propagation tool to generate N observation planes from one single shot. This is possible because Shack-Hartmann technology allows to acquire both a wavefront measurement and an intensity map at the same time. Then, from these N intensity maps, the M² value is computed -according to the standard ISO 11146- as well as other characteristics. Note that N can be any value above 10 so one can access the measurement in any plane of interest without moving and aligning the sensor.

Therefore, the measurement is faster, easier and requires less space in the lab. Advantageously, it does not require focusing lenses that can affect the optical quality of the M2 measured.

Here is an example of twelve different planes when a 553 nm circular beam is measured with the sensor CAM SQUARED:

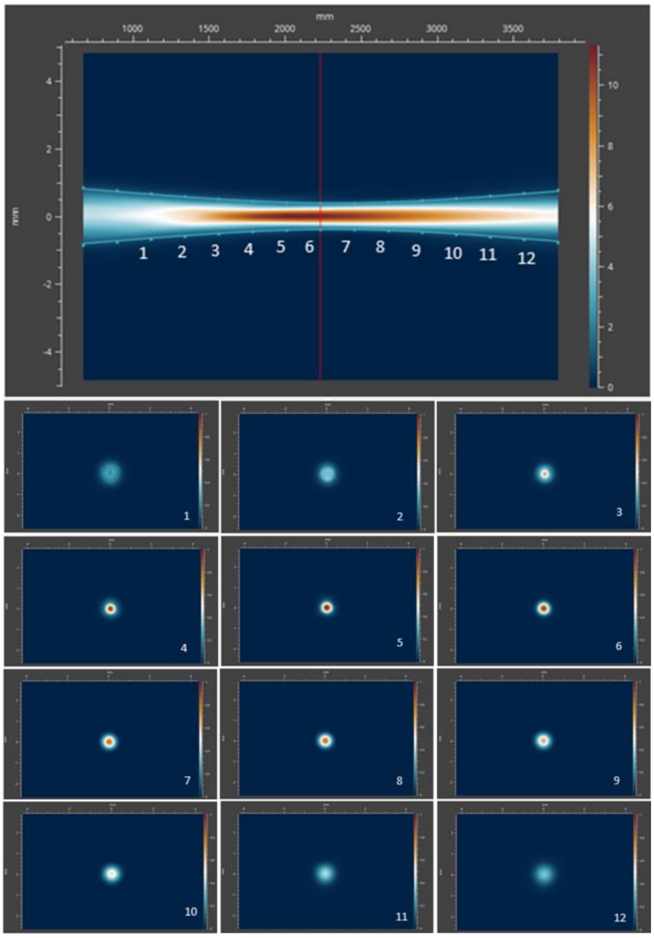


Figure 3: PSF slices in 12 different planes of a 553 nm circular laser, M² = 1.07

The main advantage of this new approach to beam quality testing is that only one shot is needed to acquire the dataset required to calculate the M² value. **Indeed, this fast measurement allows a live visualization and can therefore be used to align optical benches in R&D labs or in a production line. In addition, it can be used for the characterization of pulsed laser and dynamic effects such as thermal effects.**

II. Application 'M2': an easy-to-use interface based on WAVEVIEW™

The Application corresponds to an optimized display of laser quality metrics based on WAVEVIEW™ long-proven metrology software. It provides an instant visualization of the M² factor and of the intensity map at any observation plane. One can access this value in only one shot.

The User Interface is divided in two main parts (cf. Fig 4):
+ Diagrams (left): the first diagram represents the beam according to the yz axis. Users can move the red line in order to choose the z position on which he.she wants to visualize the xy beam intensity (second diagram below). Note that 3D plots are available too.
+ Data (right): acquisition parameters are displayed in "General information" and one can find the following metrics: M², waist position, waist size and Rayleigh distance in "Results".

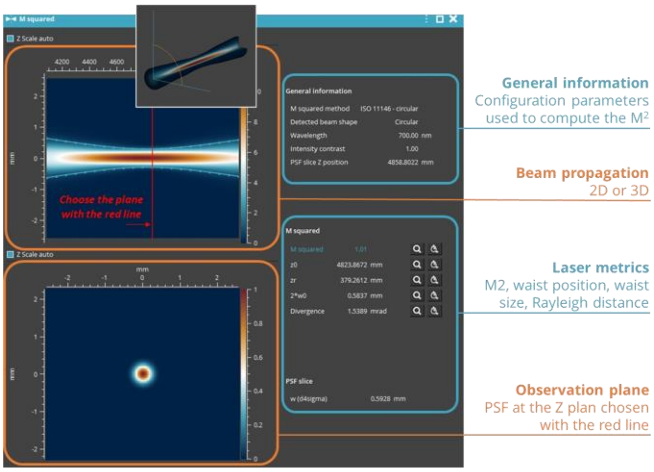


Figure 4: Application 'M²'

Users can choose the Standard ISO 11146 method according to the beam to characterize:
+ ISO 11146 – II
+ ISO 11146 – circular
+ ISO 11146 – astigmatic
+ ISO 11146 – general astigmatism

Below are screenshots of two different measurements: a perfect gaussian beam (left) and a beam with astigmatism (right). For those two beams, the Application 'M2' computes the M² values: 1.01 and 3.64.

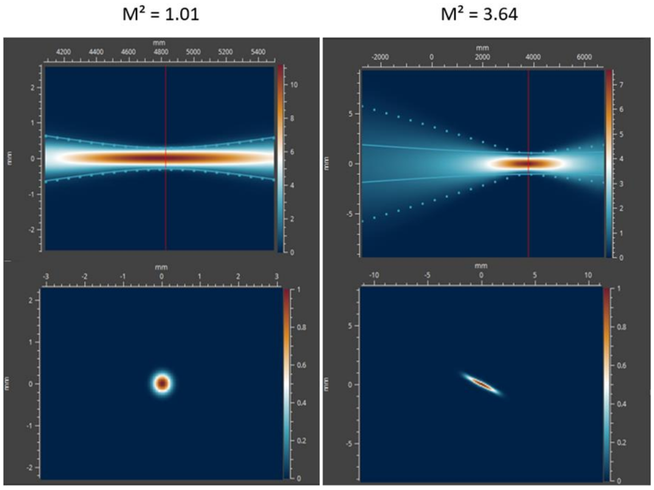


Figure 5: M² values and WAVEVIEW™ screenshots for a perfect gaussian beam (left) and an aberrated beam (right)

III. Use case with experts at Oxxius

<u>Setup:</u>
Imagine Optic works hand in hand with laser manufacturers and laser diagnostics experts to identify customers' needs and implement metrology solutions that meet their requirements. This use case reported here is the result of our collaboration with the laser manufacturer Oxxius and presents data acquired by Oxxius engineers while using the CAM SQUARED sensor with the Application 'M2' based on the version WAVEVIEW 4.3.2 to measure and reconstruct the M² on three different sources.

In order to do so, they placed each laser source in front of the wavefront sensor and adjusted the distance between them so that the analysis pupil is fully covered by the laser beam while ensuring it was not cropped.

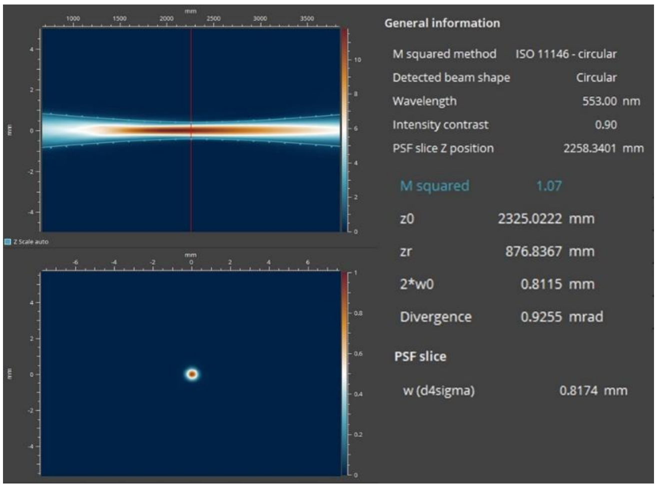
Here are the main specifications of CAM SQUARED used by laser engineers in these tests:

Pupil size (mm²)	Max frame rate (Hz)	Wavelength (nm)	Total bench size (mm³)
6.9 x 5.1	125	350 - 1100	50 x 50 x 55

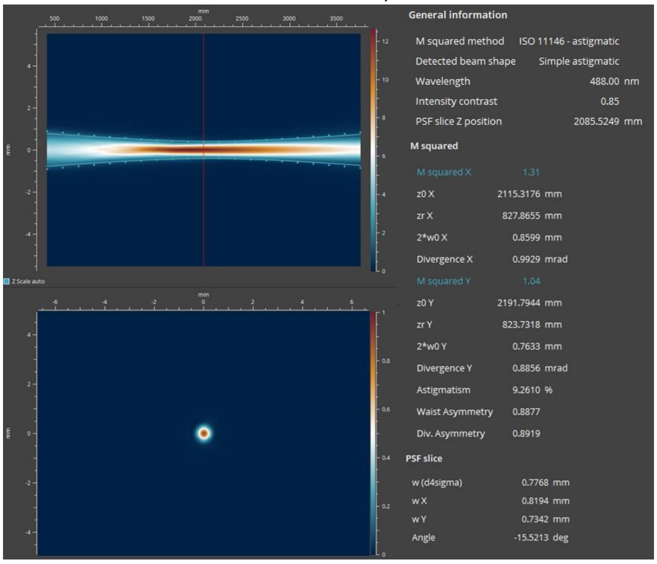
Oxxius experts used the CAM SQUARED because it is working from 350 to 1100 nm and therefore, only one sensor was used to measure the three different laser sources. **According to them, measuring the M² with this sensor was faster than their previous protocols: "only few seconds instead of more than two minutes".** Moreover, as it is a very accurate and fast wavefront sensor, it was also used to align the optical bench.

Results:

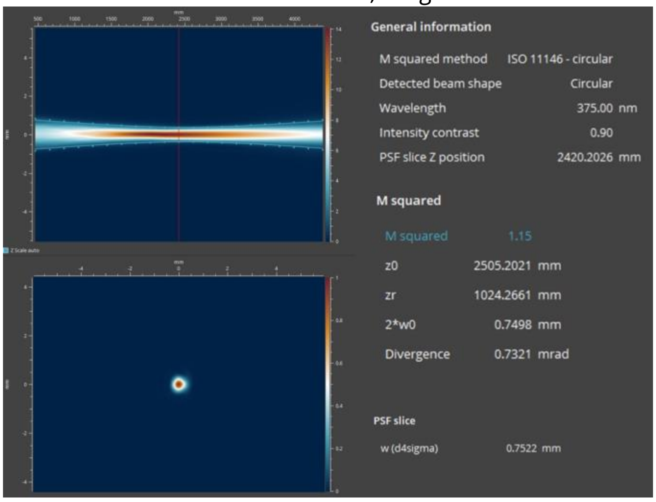
Below are reported results on different beam shapes of three different laser references:



Laser at λ = 553 nm, circular



Laser at λ = 488 nm, astigmatic



Laser at λ = 375 nm, circular

Conclusion

We report a laser diagnostic application consisting in the measurement of the M^2 parameter with a simple wavefront sensor. M^2 calculation is performed following the reconstruction proposed in the standard ISO 11146, while taking advantage of beam propagation ability of the Shack-Hartmann wavefront sensors to drastically reduce the duration of the measurement procedure. In this specific case, Imagine Optic customer reduced characterization time during production from 2 minutes to a few seconds, therefore reducing metrology costs associated to the manufactured lasers.

References

1. Standard ISO 11146: https://www.iso.org/obp/ui/#iso:std:iso:11146:-1:ed-2:v1:en

2. Imagine Optic would like to thank Oxxius team for their feedback and assistance in the acquisition of this data. Oxxius website: https://www.oxxius.com/