266nm laser beam characteristics: "Gaussian-like" approximation method

Summary: DUV 266nm generated by fourth-harmonic generation of 1064nm laser radiation into BBO crystal exhibit a complex beam profile which under certain conditions can be approximated by a Gaussian profile.

We have been developing a new "Gaussian-like" beam characterization method to allow our customers to be able to run standard beam propagation tools and get representative results process-wise.

The key elements of this method as well as typical values for standard UV microchips are presented in this note.

General considerations

266nm beams are generated by extra-cavity second-harmonic generation (SHG) of a 532nm beam in a BBO crystal.

The input 532nm profile is a quasi-purely Gaussian mode, TEM00 with typical $M^2<1.1$. However, due to the BBO crystal asymmetrical angular acceptance and strong walk-off, the output 266nm is not as ideally profiled.

Along the horizontal plane (with respect to the laser head base):

This is the direction were the BBO angular acceptance is the larger. The 266nm profile at the crystal output can be a TEM00 gaussian profile, with a generally slightly degraded $M^2 \approx 1.1$, under the right focusing conditions.
The 266nm waist size depends on focusing conditions (w=[10-20]µm range for UV microchip), and the waist position is considered to be in the middle of the BBO crystal.

Along the vertical plane (with respect to the laser head base):

The 266nm beam profile at the crystal output is close to a 700-800µm width top-hat distribution (see fig.1). Without collimating optics, the beam is thus naturally highly asymmetrical (see fig.3).

The vertical output beam width is mainly imposed by walk-off effect, not by the incident beam characteristics.

Such a top-hat profile diffracts when propagating in free-space outside the crystal : hence, its spatial profile evolves along the propagation. This is indeed not a self-diffracting distribution like the Gauss distribution.

The theoretical energy distribution in far-field is sinc² (x) = $\left(\frac{\sin(x)}{x}\right)^2$ with x being the space coordinate: there is a main dominant central lobe, surrounded by gradually decaying side lobes (fig.2). However, when observing the beam with a standard CCD camera, the side lobes are too weak to be effectively visible (fig.3).

Finally, as can be seen on fig.3, the central lobe of the sinc² function can be approximated by a Gaussian profile with a very good accuracy.

Hence, it is possible to define Gaussian-like beam parameters for the 266nm vertical beam profile, based on its far-field properties.

In the following, we will focus the discussion on the managing of this vertical axis only, the horizontal being a simple Gaussian distribution.

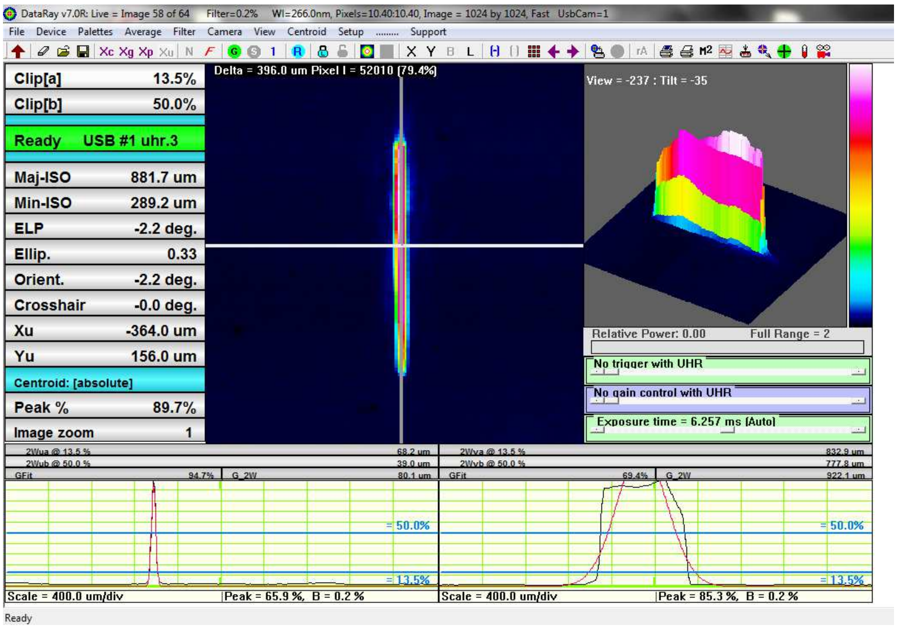

Figure 1 : Beam profile at the output of the BBO crystal

The red curves on the bottoms graphs are automated Gaussian fits : for the left picture (horizontal axis), the fit is good ; for the left picture (vertical axis), it is obviously not matching the top-hat profile

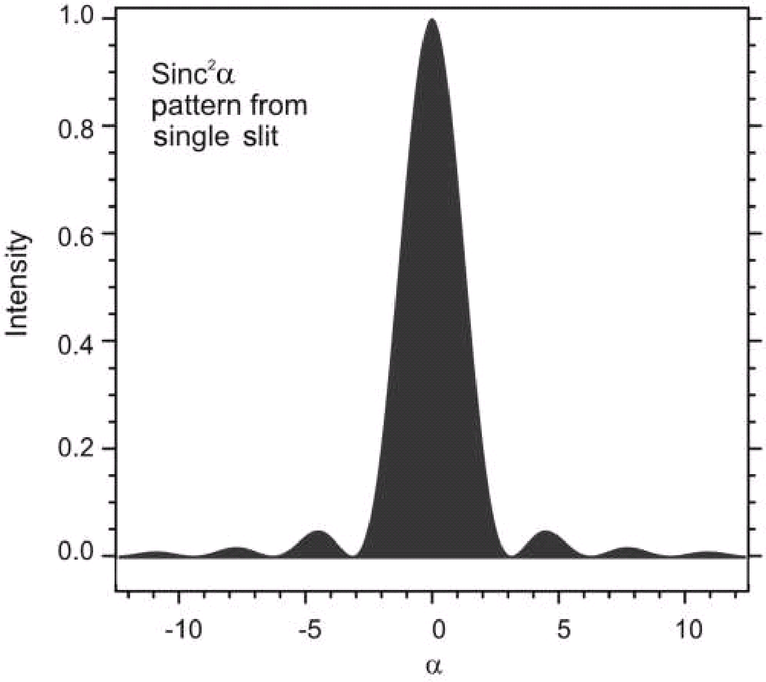

Figure 2: sinc² function

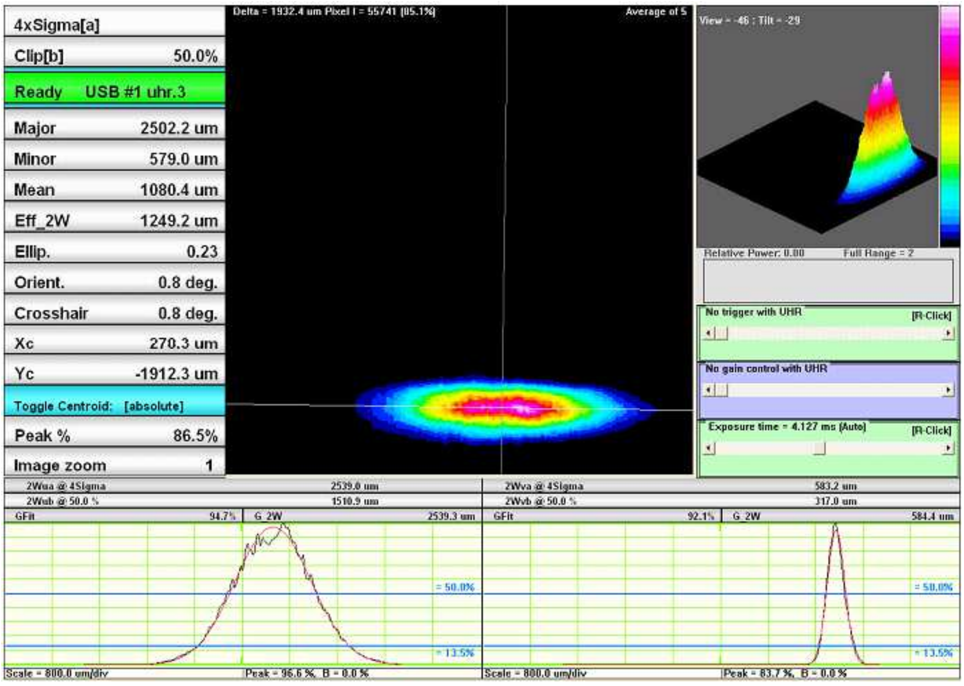

Figure 3: uncollimated free propagating beam profile in the far-field

Validity range of the "Gaussian-like" approximation for sinc² distribution

Approximating the whole sinc² distribution by the Gaussian approximation of its central lobe is meaningful because:

- the central lobe of the sinc² function owns ≈90% of the total distributed energy.
- the coefficient of determination R^2 of the central lobe Gaussian fit is predominantly over 85% for real beams in the far field.

The "Gaussian-like" approximation is valid in the far-field in free space propagation – could be several meters away from laser output for these collimated 266nm beams! – **but also near the focus of any simple optical system (lens, microscope objective,..) placed at the output of the laser.** For more complex system, the spatial filtering of the outer lobes will help matching the Gaussian approximation while going down the optical path.

This is really what makes this Gaussian-like approximation parameters useful for our customers willing to model 266nm beam propagation in their optical system : as long as the important process interaction happens in a zone close to a focus of the 266nm beam, using the approximated beam parameters allows to **run standard beam propagation tools and get representative results process-wise**.

"Gaussian-like" approximation beam parameters and how to use them

The beam parameters are measured in the image space after focusing of the free propagating 266nm beam.

The 'image waist' information is extracted from knife-edge beam width measurement in the vicinity of the image focal plane of the lens, where the beam distribution is the closest to a true sinc². Then, the far-field divergence can be accurately measured on a test bench scale, thanks to the higher divergence of the focused beam. The M^2 value is calculated from these two latter data.

Finally, the object space beam parameters – our so-called "Gaussian-like" beam parameters, representative of the free space propagating beam from the laser output – are reverse calculated from standard Gaussian transformation laws.

In the case of “large” incident beam, the object waist position doesn’t have a strong impact on the image beam parameters. For the sake of coherence, we will consider the object waist plane to be located at the output face of the BBO crystal, where the diffractive beam starts propagating in free-space.

In the end, we are able to define the set of 3 input parameters that are necessary for beam propagation simulation: waist size, waist position and M^2.
It is important to keep in mind that these parameters are not intended to give an accurate description of the beam at any plane along the propagation, but to provide a meaningful 266nm focused beam description close to the focus plane.

"Gaussian-like" beam parameters for Teem Photonics 266nm microchip lasers

The values provided here are given as indicative values. They were found during the measurement campaign. Actual data may be different and should be discuss with Teem Photonics as the case may be.

SNU-02P **without** collimation	
Horizontal axis	Vertical axis "Gaussian-like" parameters
Waist = ≈16µm	Waist = 400µm +/-50µm
M^2=1.10±0.05	M^2 =1.2+/-0.2
Waist position : -75mm from laser output	Waist position : -75mm from laser output
Direct divergence measure:	Direct divergence measure:
Full angle divergence = 11mrad +/- 2mrad	Full angle divergence = 0.5mrad +/- 0.1mrad

SNU-02P **with** collimation	
Horizontal axis	Vertical axis "Gaussian-like" parameters
Waist ≈ 400µm	Waist = 400µm +/-50µm
M^2=1.10±0.05	M^2 =1.2+/-0.2
Waist position : ≈700mm from laser output	Waist position : -75mm from laser output
Direct divergence measure:	Direct divergence measure:
Full angle divergence = 0.5mrad +/- 0.1mrad	Full angle divergence = 0.5mrad +/- 0.1mrad

SNU-20F **without** collimation	
<u>Horizontal axis</u>	<u>Vertical axis "Gaussian-like" parameters</u>
Waist = 16µm	Waist = 400µm +/-50µm
M^2=1.10±0.05	M^2 =1.2+/-0.2
Waist position : -105mm from laser output	Waist position : -100mm from laser output
Direct divergence measure:	Direct divergence measure:
Full angle divergence = 11.5mrad +/- 2mrad	Full angle divergence = 0.5mrad +/- 0.1mrad

SNU-20F **with** collimation	
<u>Horizontal axis</u>	<u>Vertical axis "Gaussian-like" parameters</u>
Waist ≈ 230µm	Waist = 400µm +/-50µm
M^2=1.10±0.05	M^2 =1.2+/-0.2
Waist position : ≈1500mm from laser output	Waist position : -100mm from laser output
Direct divergence measure:	Direct divergence measure:
Full angle divergence = 0.8mrad +/- 0.1mrad	Full angle divergence = 0.5mrad +/- 0.1mrad