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Application Note

Attenuation-Induced Error due to Thermal Lensing in Beam Measurement

Introduction

Profiling lasers with powers in the 10mW to 1W range is becoming more common. Many of these lasers are in the visible spectrum, allowing them to be measured with CCD and CMOS camera systems. As with any laser that is being measured with a camera array, the beam needs to be attenuated, but there are some cautions to be observed. These beams are not so powerful that they will damage or destroy typical absorptive filters. In fact, it is possible to stack up a sufficient optical density to reduce the power of a 1W laser to the pW levels that will not saturate the detector. Unfortunately doing this will more than likely result in erroneous measurements. This is due to a phenomenon called thermal lensing, or thermal blooming. The laser's energy heats the local area of the absorptive filter, changing its optical properties. These changes often result in changes to the refractive index of the substrate, forming a lens that may either focus or expand the beam. At lower powers, this phenomenon can be observed over discernable timeframe, hence the term "blooming." However, it may also occur almost instantly, giving the illusion of stability and accurate measurements.

There is a rule-of-thumb that says that absorptive filters may be used safely and accurately at powers that are around 100mW per mm diameter. This is roughly equivalent to a power density of 12.7W/cm^2. Since power density increases as beam size decreases, this means that a 100µm beam may show this effect at as low as 1mW of power. Of course the actual values will vary and be dependent on the wavelength. One thing is certain, though: accurate measurement with a camera array requires proper attenuation.

What is proper attenuation? Proper attenuation uses a combination of reflective and absorptive filters to reduce the beam power to the array. The first stages of attenuation should always be done with some type of reflector if the power density is likely to exceed the thermal lensing limits. These can be mirrors, prisms or front surface reflectors. If polarization is important then these reflectors should be used in pairs to maintain the polarity of the laser beam.

In this application note we will show results from measurements of a moderately powered laser (300-500mW) made with absorptive filters alone, combined reflective and absorptive filters, and with the NanoScan slit scanning profiler, which requires no attenuation for such measurements. The error in the measurements made with the absorptive filters alone is quite significant, with the beam size being underreported by as much as 40%.

Experimental Design

An unfocussed CW beam from a Coherent DPSS 532 Laser (532nm wavelength) with a nominal power of 500mW was measured using three methods.

Method 1

Using the Photon USBeamPro CMOS array beam profiler with all the attenuation provided by absorptive filters, the beam was measured at a point 30cm from the exit aperture of the laser. The attenuation comprised a 2.8OD gray-glass fixed filter and the Photon ATP-K continuously variable wedge attenuator (1.7—4.6OD).

Method 2

The first stage of attenuation was provided by using a front surface reflection with additional attenuation provided by the ATP-K. The rest of the measurement set up remained identical to that in Method 1.

Method 3

Measurements were then taken at the same measurement plane with the Photon NanoScan scanning slit profiler, which needed no attenuation for this laser.

Results and Discussion

Because we expected to see thermal effects in the initial experimental design (Method 1), we used time charting to observe the measurement of the laser. In order to see any effects and eliminate any contribution from the laser itself, we started the camera and then uncovered the laser beam. There was an immediate spike of the beam size to around 700µm. It settled to a value around 500µm ($1/e^2$) within a few milliseconds. With each measurement we saw a similar pattern, however the value of the initial spike was somewhat variable.

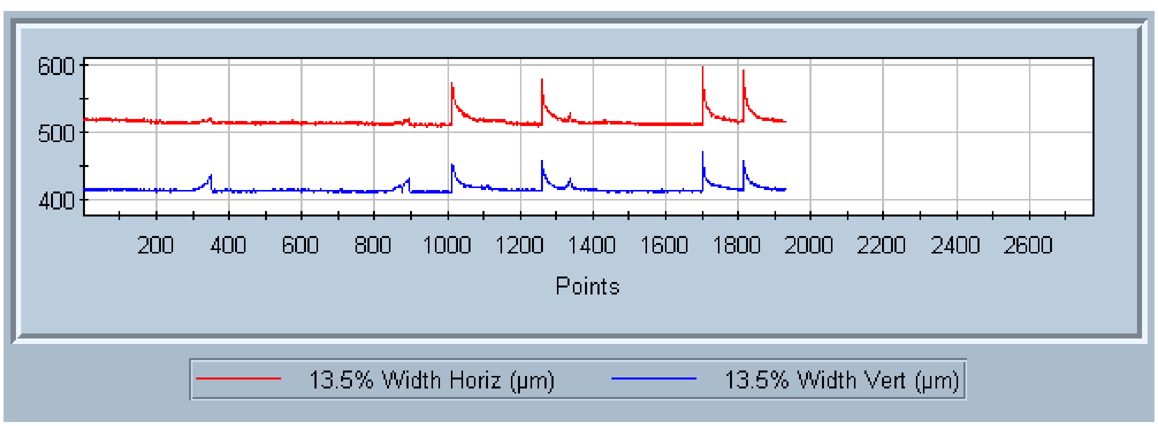

Fig. 1. Time chart of beam measurement made with absorptive attenuation only, showing initial spike of beam size with stabilization to lower value

Had time charting not been employed the measurement would have appeared to be stable at the 430-520µm beam size.

Parameter	Value	Mean	Min	Max	Std Dev
13.5% Width Horiz (µm)	512.9	515.75	507.6	596.2	9.04
13.5% Width Vert (µm)	412.6	414.88	408.5	469.0	6.65
50.0% Width Horiz (µm)	300.7	301.76	297.6	334.8	3.65
50.0% Width Vert (µm)	250.9	252.97	249.4	279.0	2.88
Centroid Horiz (µm)	2846.3	2872.75	2844.1	3292.1	21.40
Centroid Vert (µm)	4181.0	4136.37	4115.6	5002.6	32.83

Fig. 2. Data display of USBeamPro beam size measurements made with absorptive attenuation only

When this same experiment was repeated using the front surface reflection attenuator, the spiking effect was no longer visible and the beam measurement was ~850µm.

Parameter	Value	Mean	Min	Max	Std Dev
13.5% Width Horiz (µm)	849.6	848.69	846.8	850.8	0.77
13.5% Width Vert (µm)	913.9	914.75	912.3	917.6	0.94
50.0% Width Horiz (µm)	490.2	489.44	488.5	490.2	0.38
50.0% Width Vert (µm)	534.8	535.78	534.2	537.3	0.66
Centroid Horiz (µm)	4919.5	4919.71	4917.8	4923.6	1.16
Centroid Vert (µm)	3539.6	3540.69	3535.3	3544.2	1.64

Fig 3. Data display of USBeamPro beam size measurements with 4% front surface reflector and ATP-K

Measurement with the NanoScan also showed a beam size measurement of ~850µm

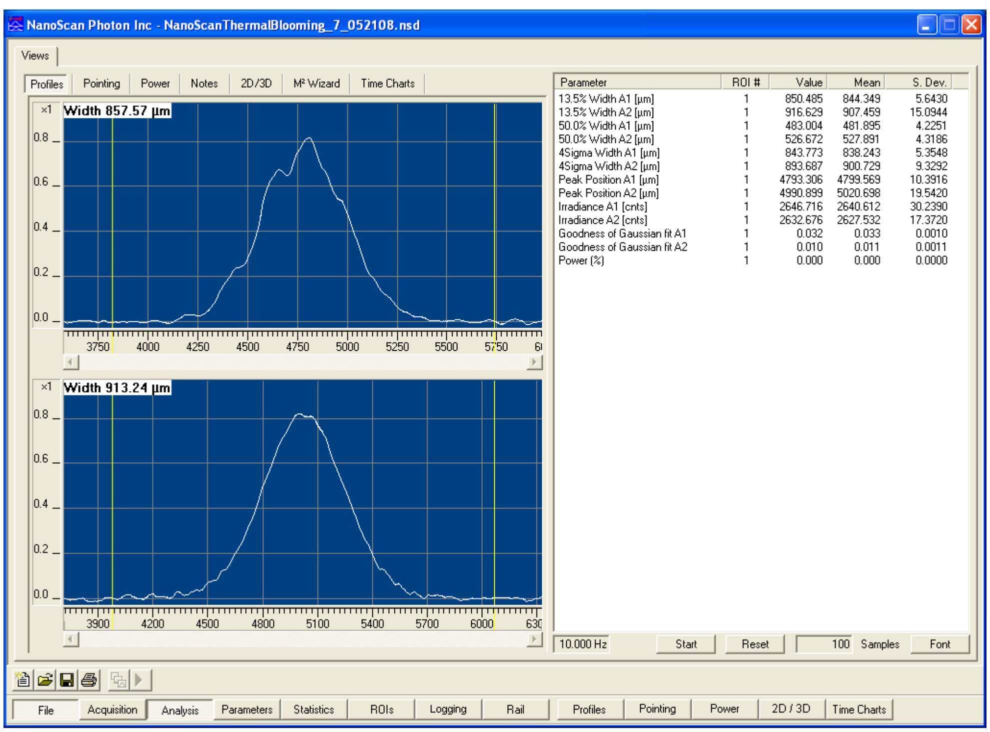

Fig 4. Data display of beam size measurements made with NanoScan Profiler

The measurements of the unaltered beam with the NanoScan and the properly attenuated beam with the USBeamPro were in agreement. The beam measurements subject to thermal lensing were 40% low, indicating that a very rapid lensing effect was taking place in the first attenuator. Because this effect is so rapid, it is quite possible for such errors to go unnoticed. The measurements did not exhibit the “blooming” effect that might we expected from a slower heating effect. Instead they achieved equilibrium within a matter of milliseconds.
The power density of this laser was ~80W/cm^2. The power going into the ATP-K attenuator after the front surface reflector was 3.2W/cm^2. It is well below the theoretical thermal lensing limit of 12.7 W/ cm^2. The comparable results from this configuration and the NanoScan confirm that thermal lensing effects do not occur once the power level is reduced below the critical limit.

Conclusion

Even though it is possible to combine enough optical density attenuation to reduce a laser to power levels that do not saturate a camera, care must be taken to do this correctly if the results are to be meaningful. Simply because thermal effects are not seen to be occurring does not mean that they are not happening. One of the strengths of the NanoScan slit-based profiler is that it does not need attenuation and thus will yield accurate results every time. It is possible to get similar results with a camera, but the attenuation scheme used must be well designed. If there is any doubt about the possibility of thermal lensing effects, it is safest to use a reflective attenuator to reduce the power levels to eliminate the uncertainty.