NS170C
Microscope Slide Peak Intensity Sensor for Two-Photon Lasers

User Guide



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Chapter 1 Introduction

1.1 Intended Use

NS170C Microscope Slide Peak Intensity Sensor for Two-Photon Lasers is compatible with all Thorlabs C-series power and energy meters. To ensure reliable operation, the unit should not be exposed to corrosive agents or excessive moisture, heat, or dust. If the unit has been stored at a low temperature or in an environment of high humidity, it must be allowed to reach ambient conditions before being connected to a Thorlabs meter.

The product may only be used in accordance with the instructions described in this manual. Any other use will invalidate the warranty.

1.2 Explanation of Safety Warnings

⚠WARNING Warning indicates a hazard with a medium level of risk that, if not avoided, could result in death or serious injury.

NOTICE Indicates information considered important, but not hazard-related, such as possible damage to the product.

CE The CE markings on the product are the manufacturer's declaration that the product complies with the essential requirements of the relevant European health, safety, and environmental protection legislation.

The symbol on the product, the accessories or packaging indicates that this device must not be treated as unsorted municipal waste but must be collected separately.

1.3 Description

The NS170C Microscope Slide Peak Intensity Sensor for Two-Photon (2P) lasers is designed to measure the relative peak power of femtosecond lasers at the focus of two-photon microscopes. The housing shares dimensions with a microscope slide and fits standard microscope objective stages in both upright and inverted setups. The sensor can handle a wide power range; however, it is only sensitive to the peak power density of focused femtosecond pulses. The maximum average power incident on the device is 350 mW; more power can result in damage to the optical components. The sensor features a 30 µm thick beta-Barium Borate (BBO) crystal to convert the incident near-infrared (NIR) pulses into visible light through second harmonic generation (SHG). For example, a small fraction of photons in 920 nm pulses are combined pair-wise by the crystal into a new pulse at half the wavelength (460 nm) and twice the photon energy. Optical filters underneath the BBO crystal reject the NIR light with high suppression, allowing only the visible second harmonic light to transmit down to the large area silicon photodiode (see Figure 1). The magnitude of the detected second harmonic light allows for the direct optimization of the pulse duration at the microscope focus. Typical signal levels of the detected second harmonic light are on the order of 100’s of µW, with a signal-to-noise ratio of roughly 10 000:1.

At the entrance to the sensor is a 170 µm thick cover glass sealed to the housing. When using water or oil objectives, the appropriate immersion medium may be placed directly on the surface of the cover glass. Any liquid used for focusing can be easily cleaned from the glass surface and the top area of the aluminum housing using the procedure outlined in Chapter 4 Maintenance and Cleaning.

There is an 80 µm air-gap between the bottom of the integrated cover glass and the BBO crystal. The air-gap is a necessary compromise, as index-matching gel or epoxy would burn in the focus of high intensity femtosecond

illumination. The total internal reflection (TIR) of the highest spatial frequencies present when using high numerical aperture (NA) objectives will reduce the NIR power incident on the BBO crystal. However, the second harmonic process in the BBO has a finite spatial frequency acceptance bandwidth, which is exceeded by high NA objectives. This means that the highest spatial frequencies rejected by TIR would not appreciably contribute to the SHG process. Therefore, direct comparisons cannot be made between objectives of differing NA in terms of their capacity to drive nonlinear processes.

The sensor only generates detectable second harmonic light when the ultrathin BBO crystal is in the focus of the objective. To minimize the possibility of damaging a component, we recommend a starting position with the sensor below the focus and slowly bringing the sensor up and into focus, keeping in mind the optimum longitudinal position is <30 µm in depth with high NA illumination. Once the focal position has been found by monitoring the power meter read out, the crystal angle can be tuned to maximize the second harmonic signal level.

The rotational orientation of the BBO crystal can be adjusted with the exposed, knurled wheel. The SHG process is sensitive to the linear polarization orientation of the incident NIR laser pulse. While some signal is typically present even in the worst crystal orientation, >10x more SHG signal and higher signal-to-noise ratio will be present with the optimized orientation.

An 8-32 and M4 x 0.7 threaded mounting hole is provided to accommodate posts and post holders. Nonvolatile memory in the sensor connector contains sensor information data and the NIST and PTB traceable calibration data. Please note that the NIST and PTB calibration is for the visible light incident on the detector; however, the magnitude of that visible light is specific to the illumination conditions of the NIR femtosecond pulses.

1.4 Technical Data

1.4.1 Specifications

Item #	NS170C
Detector Type	Second-Order Nonlinear Crystal with Silicon Photodiode
Laser Wavelength Range	780 - 1300 nm
SHG Wavelength Range	390 - 650 nm
Max Peak Power Density [a]	10 TW/cm^2
Laser Average Power Range[b]	0.5 - 350 mW
SHG Optical Power Working Range	10 nW – 5 mW
Input Aperture	Ø4.5 mm
Working Distance	0.22 mm
Linearity[c]	±0.5%
Resolution[c,d]	1 nW
Measurement Uncertainty[c,e]	±3% (440 – 650 nm) ±5% (390 – 439 nm)
Response Time	<1 µs
Sensor Dimensions	Base: 76.0 mm x 25.2 mm x 5.0 mm (2.99” x 0.99” x 0.20”) Overall: 76.0 mm x 30.0 mm x 11.0 mm (2.99” x 1.18” x 0.43”)
Cable Length	1.5 m
Connector	Sub-D 9-Pin Male
Weight	80 g
Post Mounting	Combi Thread 8-32 and M4 x 0.7
Compatible Consoles[f]	PM100D, PM100A, PM400, and PM502
Compatible Interfaces[f]	PM101x, PM103x, and PM100USB

a. The specified damage threshold is for objectives with NA > 0.5. The damage threshold will be lower for NA < 0.5.
b. The working range provided is for lasers with a repetition rate of 80 MHz. Because the peak power and peak power density are dependent on the average power and repetition rate of the laser, the upper limit to the working average power range will be lower for lower repetition rates. Exceeding the maximum average power may result in damage to the sensor’s optical components.
c. This specification is for the measured SHG signal.
d. Measured with a PM100D console in low bandwidth setting.
e. Valid for 1/e^2 beam diameters >1 mm at the photodiode sensor. Please note that the photodiode sensor is several millimeters below the BBO crystal and for high NA objectives, the beam diameter is expanded appreciably.
f. The NS170C sensor is compatible with all currently available photodiode power meter consoles and interfaces, as well as the previous-generation PM200 and PM320E consoles; it is not compatible with other previous generation Thorlabs power meter consoles.

1.4.2 Graphs

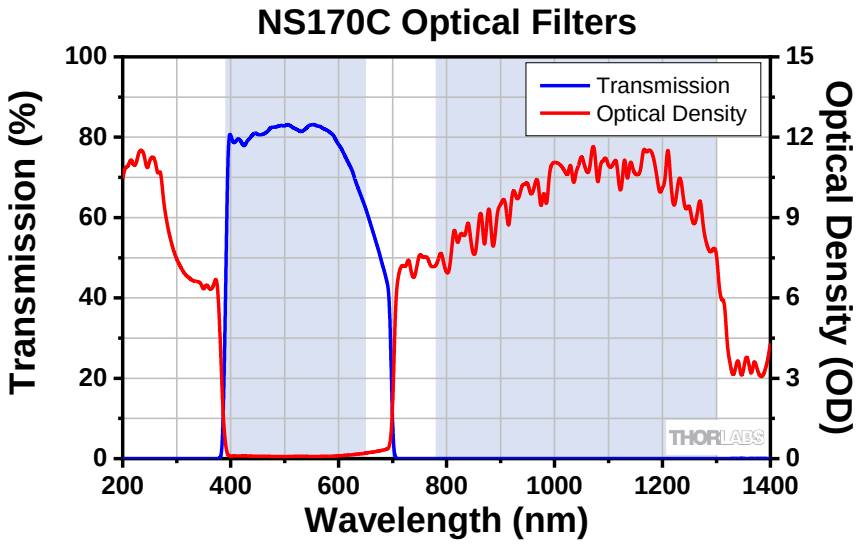


Figure 1 Transmission and Optical Density of the Optical Filters used in the NS170C Sensor[1]

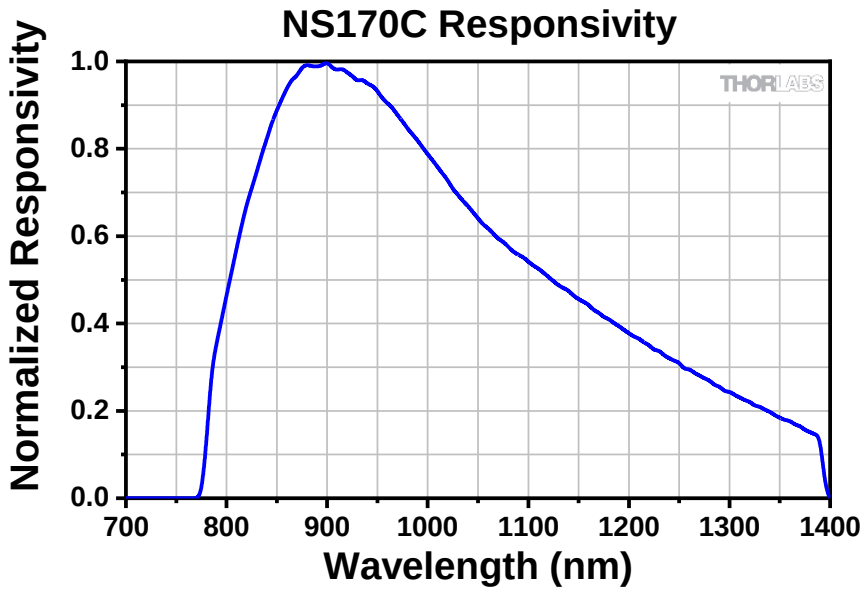


Figure 2 Theoretical Responsivity Curve of the NS170C Sensor[2]

[1]The blue highlighted regions denote the operating input laser wavelength range (780 - 1300 nm) and converted SHG wavelength range (390 - 650 nm).

[2]This is a theoretical curve that is representative of the SHG power detected as a function of the focused pulse's central wavelength. Degree level changes to the pitch, roll, and yaw of the sensor relative to the incident light can cause changes to the shape of the responsivity. Under typical laboratory conditions, the orientation of the sensor can be adjusted by-hand to optimize the SHG signal level; however, users should take note that such an optimization routine is necessary to establish long-term system performance data or global maximum SHG readings. For singular pulse optimization tasks, less care is necessary in pitch/roll optimization, as the peak power readout through the SHG signal on the power meter will respond appropriately even if off the global best orientation; however, it is still recommended to optimize the crystal rotation (yaw).

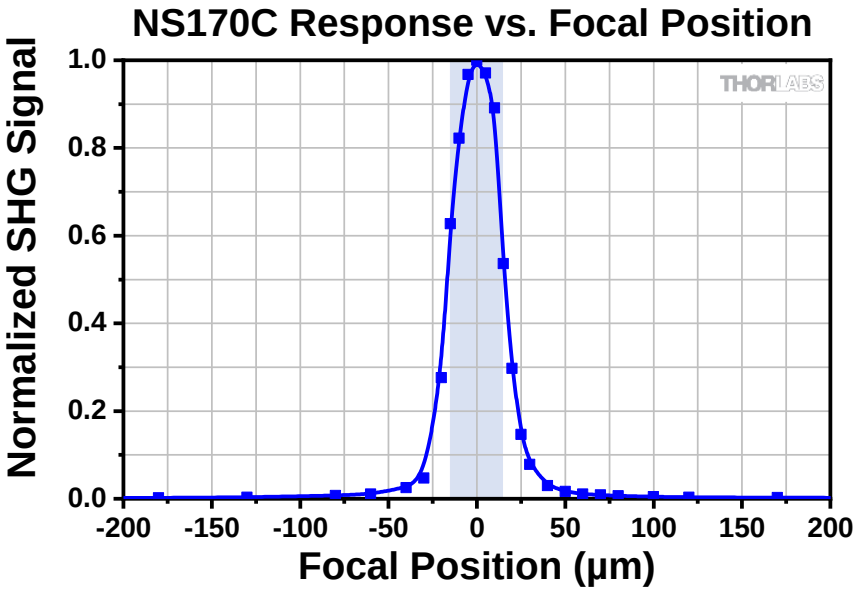


Figure 3 ***NS170C SHG Signal Response as a Function of Microscope Objective Focal Position[1]***

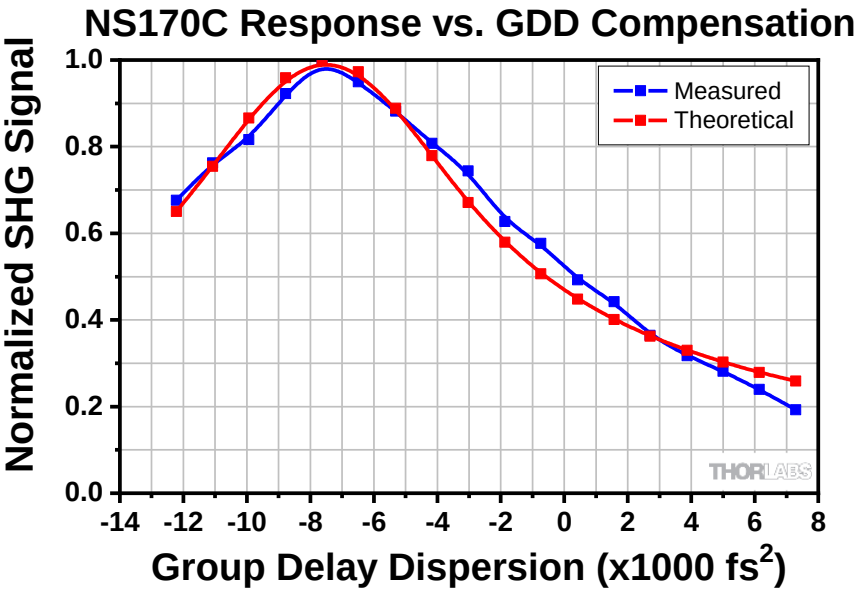


Figure 4 ***NS170C SHG Signal Response as a Function of Applied Group Delay Dispersion (GDD)[2]***

[1]Data was collected using an objective with NA = 0.5. The blue highlighted region represents the 30 µm thickness of the β-BBO crystal where the light must be focused in order for appreciable SHG conversion to occur.
[2]Data was collected for a tunable Ti:sapphire laser centered at 800 nm with 100 fs pulses, and the dispersion was adjusted using an FSPC pulse compressor.

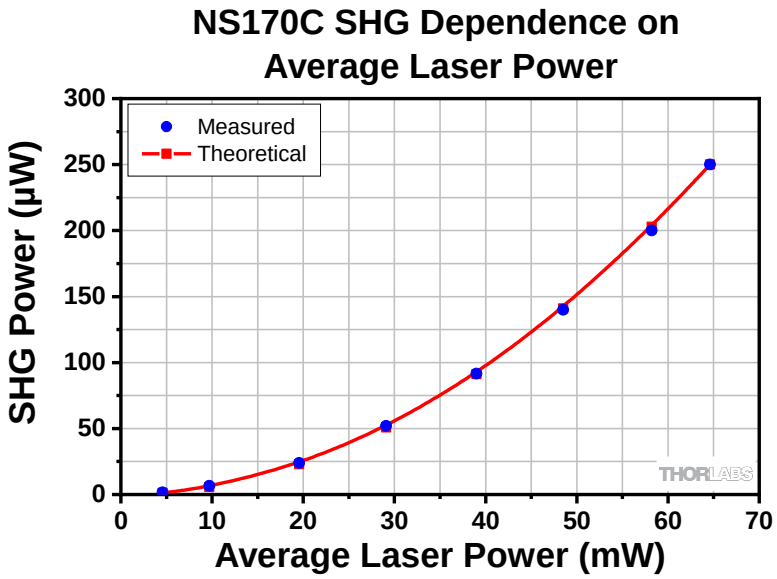


Figure 5 ***Converted SHG Power as a Function of the Input Laser's Average Power[1]***

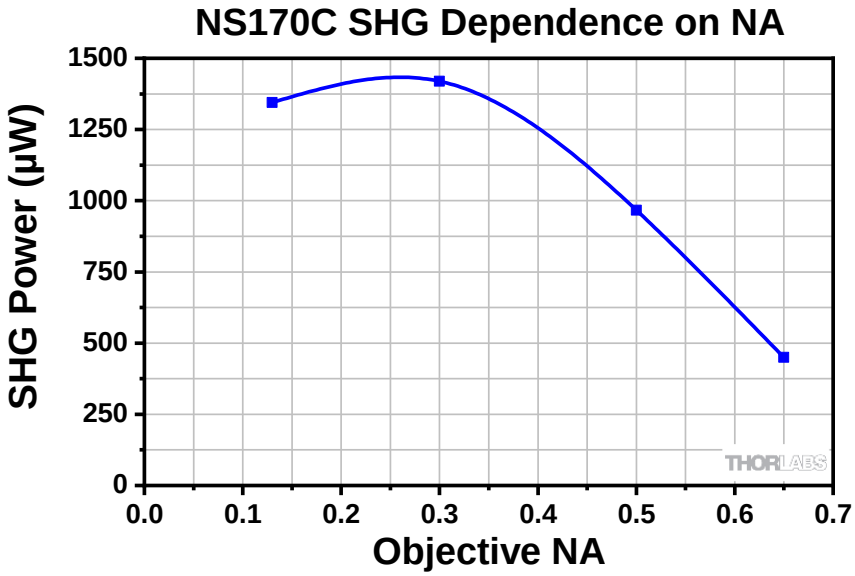


Figure 6 ***Converted SHG Power as a Function of the Microscope Objective NA[2]***

[1]Data was collected for an input laser centered at 950 nm with 56 fs pulses. The measured data agrees with the theoretical quadratic dependence of SHG conversion.

[2]The average laser power through the objective was held constant at 100 mW for each measurement and the input beam diameter was modified for a fixed fill factor of the varying entrance pupil diameters of 1.05. The spatial frequency acceptance bandwidth of the bulk β-BBO crystal is approximately equal to 0.25 NA. Objectives with an NA much larger than 0.25 will have a reduction in the amount of generated SHG signal.

1.4.3 Mechanical Drawings

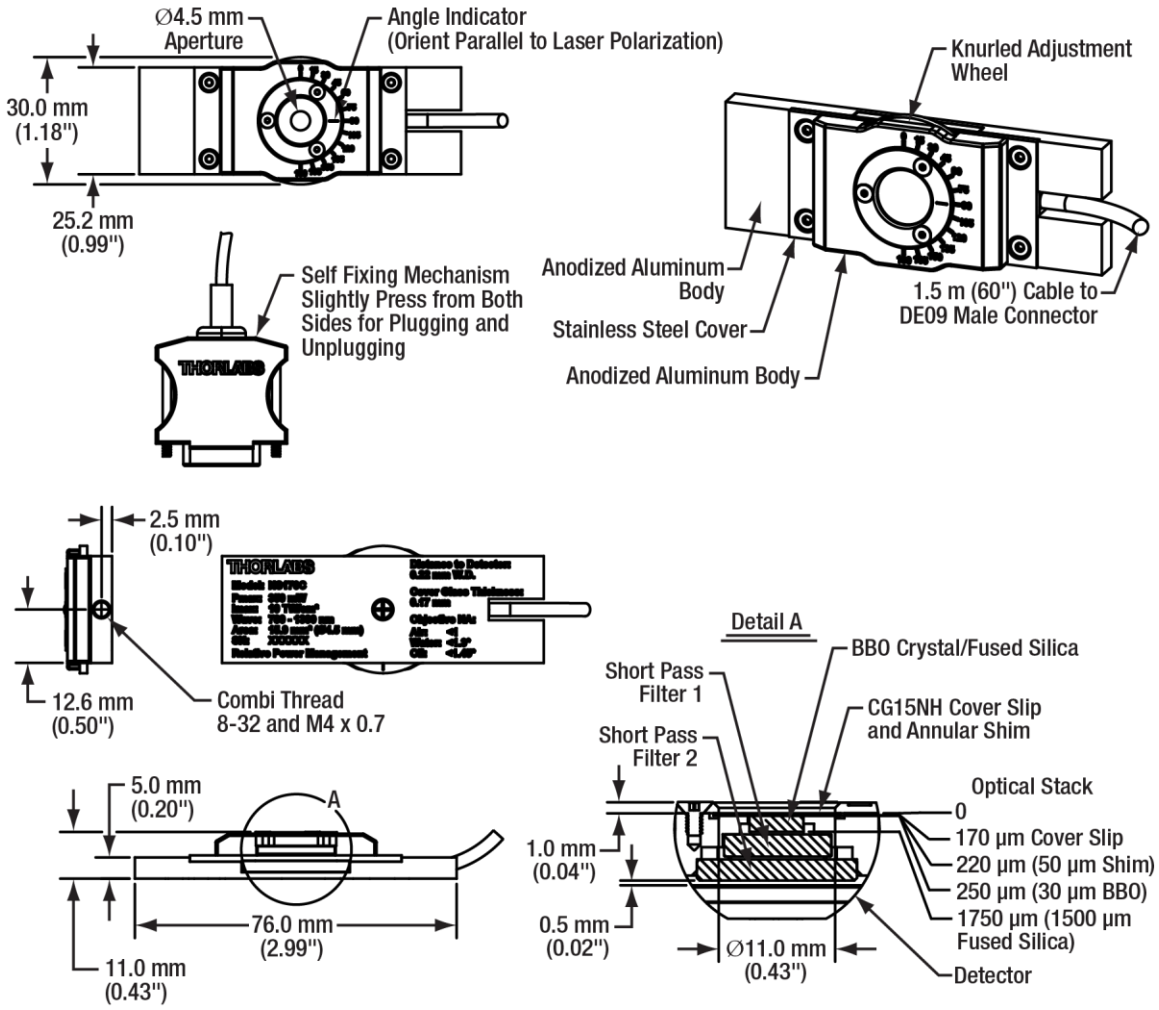


Figure 7 Mechanical Drawing

1.5 Simplified Declaration of Conformity

The full text of the EU declaration of conformity is available at the following internet address: **https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=16526**

Chapter 2 Safety

⚠WARNING

Optical Back Reflections
Back reflections from the uncoated optical entrance surface should be kept from leaving the optical table. Otherwise, effort should be made to ensure beams are not directed at the user's eyes.

NOTICE

Exceeding the maximum average power or maximum peak power density can damage the sensor and/or optical components.

Chapter 3 Operation

Setting-Up the NS170C Sensor
To set-up the NS170C power sensor:

1. Mount the NS170C to a compatible microscope slide holder or an optical post using the 8-32 (M4 x 0.7) tapped hole. To establish long-term system performance data or global maximum SHG readings, it is recommended to use a level when mounting the sensor to ensure consistency in the sensor's orientation. For singular pulse optimization tasks, less care is necessary in pitch/roll optimization, as the peak power readout through the SHG signal on the power meter will respond appropriately even if it is not the global best orientation.
2. Connect the NS170C sensor to a compatible power meter console (see Section 1.4.1).
3. Set the source wavelength on the power meter console to the wavelength of the input NIR laser.

Optimizing SHG Signal at the Focus of a Microscope
The SHG signal at the focus of a microscope can be optimized using the following procedure:

1. Find the focus of the microscope by adjusting the objective position while monitoring the output SHG signal on the power meter. The optimal objective position is reached when the SHG signal is maximized. To minimize the possibility of damaging a component, it is recommended to start with the sensor below the focus and slowly bringing the objective down (or the sensor up) until the beam is focused in the BBO crystal. Because the thickness of the BBO crystal is 30 µm, the power change during focal position optimization is observed as a brief "flash" in the SHG signal (see Figure 3). Adjustments to the objective position should be done slowly as to not miss this "flash" in signal. It can also be useful to take the power meter out of "Auto Range," since this can unintentionally obscure a fast change in measured power. In a manually set power range, the meter will simply climb to the range maximum which can be simpler feedback to interpret. You can then increase the range of the meter to perform the actual optimization of the focal position.

NOTICE The optimum longitudinal position of the focused light is <30 µm in depth. The converted second harmonic light is observed as a brief "flash" in the power meter readout, and focusing should be performed slowly.

2. If the polarization state of the NIR laser is known relative to the NS170C sensor, then you can tune the knurled wheel on the sensor such that the angle indicator dash mark is parallel with the polarization. The crystal rotation orientation is referred to as yaw, to differentiate it from pitch and roll.

3. If the polarization state of the NIR laser is unknown relative to the NS170C sensor, then tune the orientation of the BBO crystal by adjusting the knurled wheel on the NS170C sensor while monitoring the output SHG signal on the power meter. The optimal crystal position is reached when the SHG signal is maximized.

4. For global maximization of the SHG signal, you can make small adjustments to the pitch and roll of the NS170C sensor. In practice, optimization is only necessary along one of these axes and is along an axis parallel to the angle indicator. When tuning the pitch/roll, you can make small changes by hand and then re-optimize the focal position, as the pitch/roll will usually move the NS170C sensor relative to the focal

plane. Optimization of the pitch/roll can increase the maximum SHG signal by 2-3x for wavelengths on the edges of the wavelength range. This optimization is not necessary for optimizing the system GDD; however, if consistency between measurements is desired, this orientation needs to be either maximized or otherwise controlled, e.g. inspection with a small level.

5. Tune the pulse duration by adjusting the GDD of the pulse compressor or built-in laser GDD pre-compensation while monitoring the output SHG signal on the power meter. The optimal pulse duration is reached when the SHG signal is maximized (see Figure 4).

Typical Performance of the NS170C Sensor

The converted SHG signal of the NS170C peak power sensor is highly dependent on the experimental conditions. The wavelength, pulse duration, quality of the temporal pulse profile, NIR laser repetition rate, and power of the NIR input laser (see Figure 5) in addition to the objective numerical aperture (see Figure 6) and immersion all contribute to the magnitude of the converted visible SHG signal. The table below describes the typical performance of the NS170C peak power sensor under various experimental conditions and can be used as a reference when evaluating the expected SHG signal for a given experiment.

<table>
<tr><th colspan="6">NS170C Typical Performance[a]</th></tr>
<tr><th>Immersion</th><th>Laser Power[b]</th><th>Wavelength</th><th>Pulse Duration</th><th>Objective</th><th>SHG Signal</th></tr>
<tr><td rowspan="9">Air</td><td rowspan="7">100 mW</td><td>780 nm[c]</td><td>80 fs</td><td rowspan="3">20X, 0.5 NA[f]</td><td>980 µW</td></tr>
<tr><td>800 nm[c]</td><td rowspan="2">100 fs</td><td>1100 µW</td></tr>
<tr><td>900 nm[c]</td><td>960 µW</td></tr>
<tr><td>920 nm[d]</td><td rowspan="2">150 fs</td><td>10X, 0.3 NA[g]</td><td>216 µW</td></tr>
<tr><td>920 nm[e]</td><td>10X, 0.5 NA[h]</td><td>580 µW</td></tr>
<tr><td>1000 nm[c]</td><td>180 fs</td><td rowspan="2">20X, 0.5 NA[f]</td><td>400 µW</td></tr>
<tr><td>350 mW</td><td rowspan="2">800 nm[c]</td><td rowspan="2">100 fs</td><td>5500 µW</td></tr>
<tr><td>Water</td><td>100 mW</td><td>40X, 0.8 NA[i]</td><td>255 µW</td></tr>
</table>

a. This table is to only to be used as a reference guide. Please see the Specifications in Section 1.4.1 for full performance details.
b. The laser power measured out of the objective.
c. A tunable Ti:sapphire laser was used for this measurement.
d. A commercial 920 nm fixed laser with 80 MHz repetition rate and <100 fs transform limited pulses was used for this measurement.
e. A commercial 920 nm fixed laser with 80 MHz repetition rate and <150 fs transform limited pulses was used for this measurement.
f. Olympus Plan Fluorite 20X Objective, 0.5 NA (Item # RMS20X-PF)
g. Nikon Plan Fluorite 10X Objective, 0.3 NA (Item # N10X-PF)
h. Thorlabs Apochromatic 10X Objective, 0.5 NA (Item # TL10X-2P)
i. Nikon Apochromatic 40X Objective, 0.8 NA (Item # N40X-NIR)

It is important to note that while TIR of the highest spatial frequencies occurs when using high NA objectives due to the air-gap between the cover glass and the BBO crystal, the second harmonic process in the BBO has a finite spatial frequency acceptance bandwidth, which is exceeded by high NA objectives. This means that the highest spatial frequencies rejected by TIR would not appreciably contribute to the SHG process.

More generally, the spatial frequency acceptance bandwidth of the bulk BBO crystal in the NS170C sensor is approximately equal to a 0.25 NA. Objectives with numerical apertures much larger than 0.25 will have a reduction in the amount of generated SHG signal and therefore a smaller reported SHG power. Data comparing the SHG signal from several objectives of increasing NA is shown in Figure 6, illustrating the non-intuitive reduction in SHG

measured from a bulk crystal with increasing NA. It is important to note that the reduced signal at higher NA objectives does not reduce the utility of the device in optimizing the system for maximum imaging performance. This is a limitation of SHG in macroscopic bulk crystals and not an indication that a higher NA objective produces less two-photon absorption or second- and third-harmonic generation from microscopic targets, e.g. collagen fibrils or intracellular membranes.

NOTICE

Direct comparisons cannot be made between objectives of differing NA in terms of their capacity to drive nonlinear processes since the SHG phase matching process is itself sensitive to NA, unlike two-photon absorption.

Chapter 4 Maintenance and Cleaning

There are no serviceable parts in the NS170C sensor head. The housing may be cleaned by wiping with a soft damp cloth. When cleaning the cover glass, treat it as any other fine optic. Gently blow off any debris using compressed air and wipe gently with an optic tissue wetted with isopropanol. If you suspect there is a problem with your NS170C sensor, please contact Thorlabs and an engineer will be happy to assist you.

As long as the sensor is not subjected to excessive optical power (see Specifications in Section 1.4.1), the calibration should be very stable over long periods of time. However, to ensure accuracy, the detector should be calibrated once a year.

Chapter 5 Troubleshooting and Repair

Below are a few checks to help in troubleshooting problems that may arise. Please contact your local Thorlabs Technical Support office with any questions.

If you cannot find the SHG power signal or the SHG power signal is low, follow the directions below in order.

1. I can't get any SHG signal:
    a. Ensure the meter has connected to the NS170C sensor and is reporting some non-zero power.
    b. Check that laser light is entering the objective. Even better, ensure the expected amount of average power is leaving the objective. This will require temporarily removing the NS170C from underneath the objective.
    c. Move the NS170C sensor below the focal plane of the objective. It is better to be conservative and move it well below.
    d. Slowly translate the NS170C sensor towards the focal plane. Note that the SHG signal will appear and disappear within a very small positional window. For high NA objectives, this will be 30 µm in width. If the power meter is set to Auto Range, the signal can sometimes get missed when the meter attempts to change ranges. It can be advantageous to set the Range to something that is zoomed in on the initial signal, e.g. <10 µW, then as you translate through the focus you will see the meter "rail" at the max of that range. You can then pause and adjust the Range appropriately.
2. I have SHG signal, but it is different than before:
    a. Is the wavelength setting in the power meter the same as before? If not, set the meter for the NIR laser wavelength.
    b. Is the laser wavelength the same as before, an especially important detail for tunable lasers?
    c. Is the laser group delay dispersion compensation the same as during previous measurements?

d. If there are new optics in the microscope beam path, then the laser pulse group delay dispersion compensation will need to be updated for the new system configuration.

e. Perform steps 1b through 1d above.

f. Did the laser polarization state change from before?

g. Check the crystal orientation. If you made a note of the previous orientation, return the NS170C sensor to this condition. If the mount or holder for the NS170C has changed orientation relative to the microscope, then the optimum crystal orientation will change.

h. Is the pitch/roll of the NS170C sensor the same under the objective? This can have a strong impact on the maximum SHG signal, 2-3x.

Chapter 6 Disposal



Thorlabs verifies our compliance with the WEEE (Waste Electrical and Electronic Equipment) directive of the European Community and the corresponding national laws. Accordingly, all end users in the EC may return “end of life” Annex I category electrical and electronic equipment sold after August 13, 2005 to Thorlabs, without incurring disposal charges. Eligible units are marked with the crossed out “wheelie bin” logo (see right), were sold to and are currently owned by a company or institute within the EC and are not dissembled or contaminated. Contact Thorlabs for more information. Waste treatment is your own responsibility. “End of life” units must be returned to Thorlabs or handed to a company specializing in waste recovery. Do not dispose of the unit in a litter bin or at a public waste disposal site. It is the user’s responsibility to delete all private data stored on the device prior to disposal.

Chapter 7 Thorlabs Worldwide Contacts

For technical support or sales inquiries, please visit us at www.thorlabs.com/contact for our most up-to-date contact information.



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