AEROGAIN-ROD 2.1, 3.1 & 3.2

High-power ytterbium rod fiber gain module

MAY 25

USER GUIDE
HANDLING AND COUPLING INSTRUCTIONS

This document contains critical information on how the aeroGAIN-ROD unit should be handled, installed and used. It is important that this document is read and understood before taking the aeroGAIN-ROD into use.

You can find additional resources on the NKT Photonics website, where a datasheet containing specifications, and a 3D model (.STEP) file for the modules can be downloaded.

This instruction covers the aeroGAIN-ROD 2.1, 3.1 and 3.2 with the following main distinctions between the modules:

- The aeroGAIN-ROD 2.1 has a gain fiber length of approximately 804 mm and supports an average signal power of ≤ 100 W with an optical efficiency of ≥ 60%*
- The aeroGAIN-ROD 3.1 has a gain fiber length of approximately 804 mm and supports an average signal power of ≤ 250 W with an optical efficiency of ≥ 60%*
- The aeroGAIN-ROD 3.2 has a gain fiber length of approximately 604 mm and supports an average signal power of ≤ 150 W with an optical efficiency of ≥ 40%*

  **Under nominal operation: Seed level 5 W @ 1030 nm, 976 nm pumping*

The aeroGAIN-ROD module is the ultimate high-power fiber amplification module for ultrafast pulsed lasers. With its 3300 μm^2 mode field area and high pump absorption, it gives you a power handling previously only available in solid-state configurations.

The aeroGAIN-ROD enables single-mode operation with large mode area to ensure diffraction limited beam quality and optimum pointing stability. The aeroGAIN-ROD is designed and qualified to amplify signals around 1030 nm.

The rugged aluminum body makes the module easy to handle and mount for OEM integration and scientific laboratory setups.

Figure 1 shows a picture of the aeroGAIN-ROD modules.

Figure 1: aeroGAIN-ROD 2.1, 3.1 and 3.2

Key features

- Diffraction-limited beam quality
- High NA pump cladding
- High peak power damage threshold
- AR coated endcaps
- Optimized for approximately 1030 nm
- Compact and robust industrial format
- PM amplification
- Long lifetime

The aeroGAIN-ROD module

The ROD fibers are delivered mounted as aeroGAIN-ROD modules ensuring easy and secure handling as well as easy mounting and coupling, see Figure 1. This ready-to-use solution ensures ROD fiber mounting without introducing any stress and protects the ROD fiber from the outer environment. The module has integrated water cooling with quick coupling, giving efficient thermal management and long maintenance-free lifetime of thousands of hours. Figure 2 shows a close look at both ends of the aeroGAIN-ROD module, while Figure 3 provides a full view of the three different aeroGAIN-ROD modules.

The aeroGAIN-ROD module has undergone extensive testing with respect to climate change, vibration, and drop testing, and is very robust against transport and storage conditions.

Figure 2: Close look at both ends of the aeroGAIN-ROD

Figure 3: Full view of the aeroGAIN-ROD 3.2, 3.1 and 2.1

aeroGAIN-ROD end facets

The aeroGAIN-ROD is equipped with two AR coated endcaps to avoid end facet damage and reflections. Figure 4 shows a picture of an end-capped ROD fiber. The aeroGAIN-ROD angled endcap orientation in the module is as shown in Figure 5.

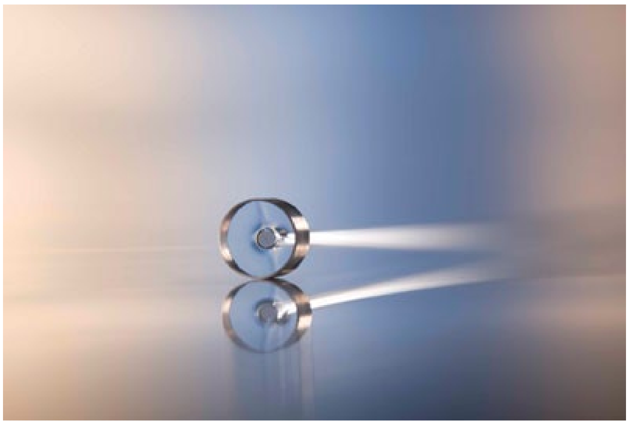

Figure 4: End-capped ROD fiber

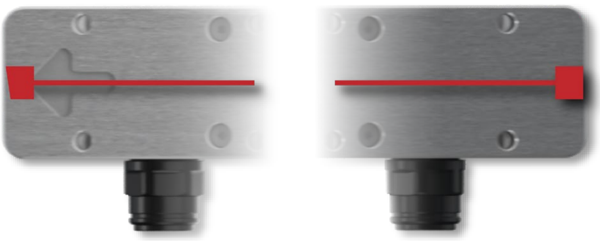

Figure 5: Approximate position of the ROD fiber with its endcap orientation in the aeroGAIN-ROD module

The aeroGAIN-ROD should be handled with great care using gloves and making sure not to touch the end facets. We highly recommend operating the aeroGAIN-ROD in a clean environment to avoid contamination of the endcaps.

The endcap covers are designed to protect the endcaps from contamination. It is recommended to keep them on the module when not in use, see Figure 6 and Figure 7.

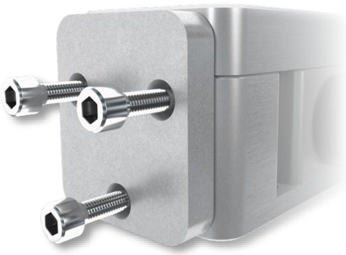

Figure 6: Covered endcap

Figure 7: Exposed endcap

Mounting the aeroGAIN-ROD

In the setup, the aeroGAIN-ROD should be supported along the full-length during operation to avoid bending induced stress and movement, and carefully secured to the holder without introducing stress, as this can degrade performance of the ROD fiber.

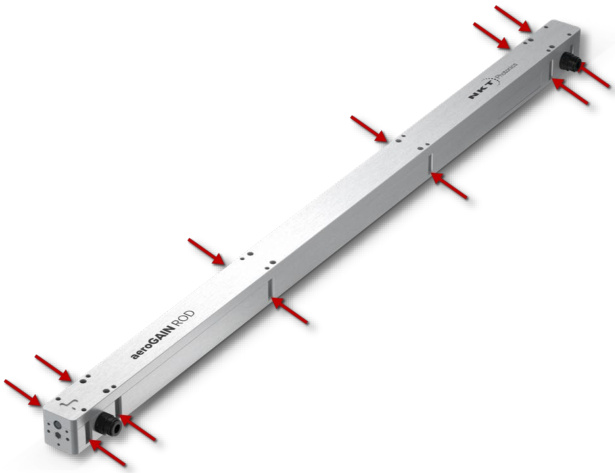

Figure 8: Mounting holes

We recommend using M3 caps head screws in the 12 holes designed for the purpose, see Figure 8. Ensure flatness of the module when mounted and operated for heat dissipation and stability. Alternatively the 4 M6 threads under the modules can be used, see Figure 9 – this is however not our recommended solution.

Figure 9: Alternative mounting

The aeroGAIN-ROD fiber is designed for water cooling – see the datasheet for water cooling recommendations.

COUPLING AND INTERFACING GUIDE

Prerequisites

Before taking the aeroGAIN-ROD into use, there are several prerequisites to ensure optimal conditions. This involves a test assessing these parameters:

- Core/clad power ratio (CCR)
- Mode field diameter (MFD)
- Polarization extinction ratio (PER)
- Beam quality (M^2)
- Optical efficiency
- Beam and polarization stability

The following sections cover coupling of the aeroGAIN-ROD, beam diagnostics, as well as an example of a setup for testing the aeroGAIN-ROD, see Figure 10.

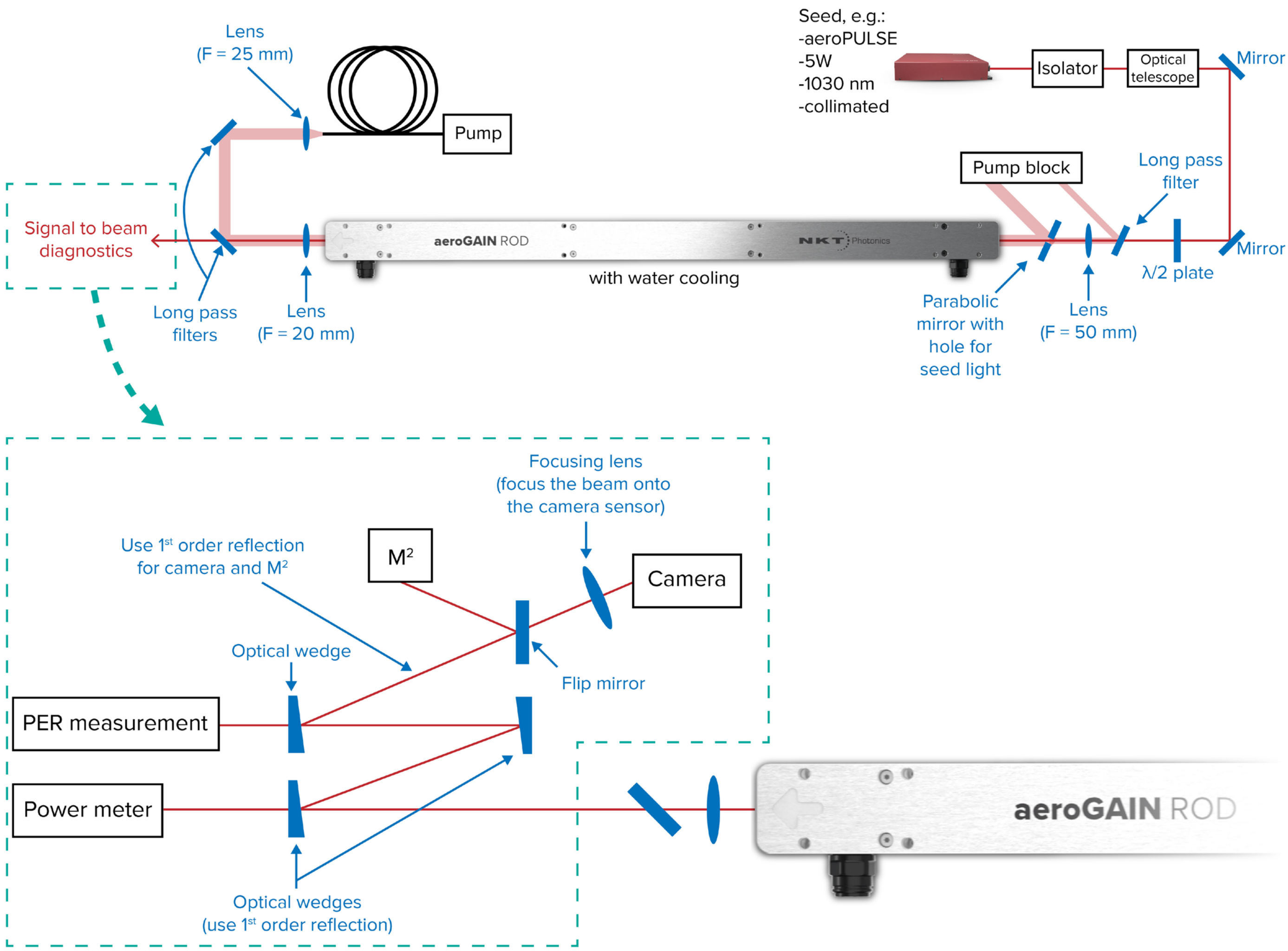

Figure 10: Setup for testing the aeroGAIN-ROD

Seeding and pumping the aeroGAIN-ROD

The beam quality of the aeroGAIN-ROD is optimized at 1030 nm to deliver diffraction limited beam quality. The ROD fiber also has the highest gain in this wavelength region.

Ensuring good seed performance is important to obtain the best results, such as e.g. beam quality and PER.

The aeroGAIN-ROD has a ≈ 260 µm pump cladding diameter with ≥ 0.50 NA supporting easy implementation of typical/off-the-shelf pump systems delivering ≈ 976 nm pump light out of a 200 µm fiber and 0.22 NA.

It is recommended to use a moderate gain in the range of 13-15 dB (up to 17 dB for the 3.1 version) when operating the aeroGAIN-ROD. As an example, for an aeroGAIN-ROD 3.1 used at its maximum recommended average power of 250 W, we recommend a seed of minimum 5 W.

A center pump wavelength of 976 nm with 1-5 nm linewidth provides the best efficiency.

Using the aeroGAIN-RODs with a maximum of 250 kW output signal peak power is recommended to ensure high reliability and a lifetime of several thousands of hours.

Recommended operating conditions

The aeroGAIN-ROD laser performance will depend on the overall laser design and how the aeroGAIN-ROD is operated. The aeroGAIN-ROD can be operated across a wide range of laser parameters.

Recommended operating parameters depends highly on the exact system parameters, the quality of the configuration and fulfilling performance requirements.

See Table 1 and Table 2 below for examples of recommended operating parameters for counter propagating operation of the aeroGAIN-ROD-3.1 for chirped-pulse-amplification and ps-pulse-amplification, ensuring high reliability. Find more information under the Reliability section of this document.

Parameter	Value	Unit
Seed wavelength	1030	nm
Seed linewidth	≈ 6	nm
Seed input power	25	W
Seed PER	≥ 20	dB
Seed pulse width	1500	ps
Seed repetition rate	0.75	MHz
Pump wavelength	≈ 976	nm
Pump linewidth	0.3	nm
Signal power	250	W
Signal peak power	≈ 220	kW
ROD fiber gain	≈ 10	dB
Optical-to-optical efficiency	≈ 65	%

Table 1: Example of recommended operating parameters for chirped-pulse-amplification

Parameter	Value	Unit
Seed wavelength	1030	nm
Seed linewidth	≈ 1	nm
Seed input power	5	W
Seed PER	≥ 15	dB
Seed pulse width	20	ps
Seed repetition rate	80	MHz
Pump wavelength	≈ 975	nm
Pump linewidth	3	nm
Signal power	250	W
Signal peak power	≈ 150	kW
ROD fiber gain	≈ 17	dB
Optical-to-optical efficiency	≈ 65	%

Table 2: Example of recommended operating parameters for ps-pulse-amplification

Rod coupling using core/clad ratio

To optimize coupling to the rod, it is important to maximize the core/clad ratio (CCR). CCR is a measure of coupling efficiency to the signal core and can be measured without gain with values depending on seed wavelength due to differences in core absorption. For the aeroGAIN-ROD, the CCR is defined as the fraction of light in a 90 µm aperture over total amount of light.

The easiest solution to measure CCR is by using a pinhole in front of a power meter. However, we highly recommend using a near field imaging setup to do so, since this will offer better accuracy. Camera based CCR allows for precise definition of the core aperture (= 90 µm) and is a better tool to achieve optimum alignment, see more details under the Camera setup section.

CCR optimization

Optimizing the seed coupling by maximizing the signal CCR with no pump light is one of the most critical steps to ensure the best possible performance and long-term reliability.

Use two coupling mirrors to optimize the coupling in combination with adjusting the mode size at the facet of the ROD fiber on the seed input side. It is recommended to use an optical telescope with a carefully chosen set of lenses to adjust the mode size of the input beam.

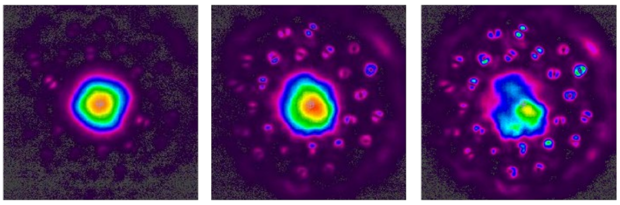

Figure 11: Example of near field images of the same aeroGAIN-ROD, passive with a 90 µm core aperture. *left:* good coupling (CCR ≈ 84 %). *middle:* poor coupling (CCR ≈ 67%). *right:* poor coupling (CCR ≈ 54%). *(note: color scale is not linear and enhances low counts)*

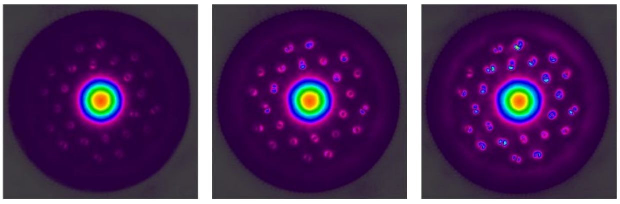

Figure 12: Example of near field images of the same aeroGAIN-ROD, passive with a 90 µm core aperture. *left:* good coupling (CCR ≈ 90 %). *middle:* poor coupling (CCR ≈ 72%). *right:* poor coupling (CCR ≈ 52%). *(note: color scale is not linear and enhances low counts)*

As a starting point in the CCR optimization it is recommended to have a mode field diameter (MFD) of ≈ 65 um with a flat phase front at the ROD fiber facet. The final MFD can differ from the initial value, which is acceptable if the CCR is optimized to give the highest possible value.

The maximum achievable passive CCR is highly dependent on seed parameters and quality. For a 5 W 1030 nm seed, we achieve a typical passive CCR of 80-90 % for the aeroGAIN-ROD 2.1, 3.1 and 3.2.

Figure 11 and Figure 12 show examples of good and bad passive CCR with two different seeds.

We recommend not to start testing the aeroGAIN-ROD actively with pump light before the maximum CCR is reached and before reading the following sections.

Camera setup

Near field imaging of the aeroGAIN-ROD core mode can be achieved by inserting a beam sampler before the power meter and sending a fraction of the light towards a CCD camera. Figure 10 shows an example of implementation. The choice of lenses is important to ensure sufficient resolution across the code mode. We recommend a minimum of 300x300 pixels area to cover the entire cladding mode. The pixel scale should be calibrated to ensure accurate MFD measurements.

It is important to adjust the camera sensor image-plane to the fiber facet, and it is also important to do a background calibration of the image to get an accurate CCR value. The MFD depends highly on operating conditions.

Polarization

We recommend monitoring the polarization extinction ratio (PER) of the signal core light. Figure 10 shows an example of implementation. We recommend having a vertically or horizontally linearly polarized seed light. A halfwave plate is placed on the seed input side to align the polarization into the ROD fiber. An iris can eventually be inserted in front of the PER measurement setup for collecting the core signal light only.

The ROD fiber maintains the input polarization through the ROD fiber. The polarization alignment is mostly dictated by the seed polarization and the optical properties of all the other optical components.

We typically observe a passive PER well above 15 dB.

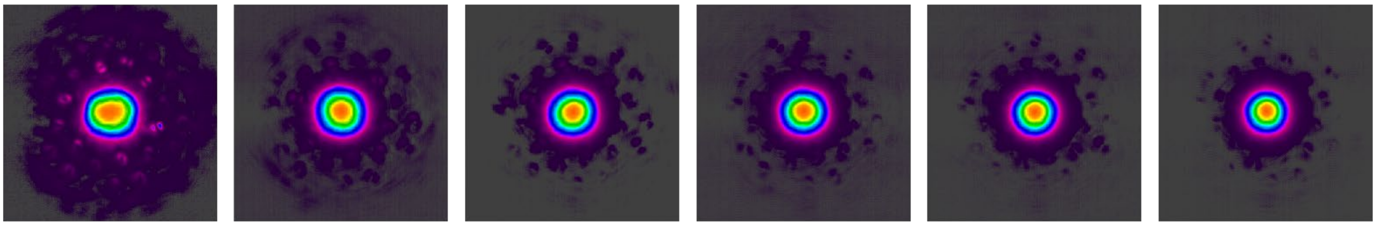

Figure 13: Example of near field images for different signal output power, measured for the aeroGAIN-ROD 3.1
From left to right: passive (seed only), 51 W, 100 W, 154 W, 207 W and 255 W
(note: color scale is not linear and enhances low counts)

ROD amplification

Once it has been ensured that the aeroGAIN-ROD is well mounted, that you have obtained good seed coupling, and you have a stable system, the aeroGAIN-ROD can be operated with pump light as an amplifier (so-called active operation).

This section features a set of data of an aeroGAIN-ROD 3.1 that represents a typical distribution for this product. The different parameters have been measured using the setup presented in Figure 10, with both the passive measurement (no pump light) and the active measurements at different signal output powers.

The aeroGAIN-ROD 2.1 and 3.2 show similar behavior.

Figure 13 shows near field images for different signal output powers.

Figure 14 shows a typical example of how the CCR improves with signal output power. It is expected to obtain an active CCR close to 100%.

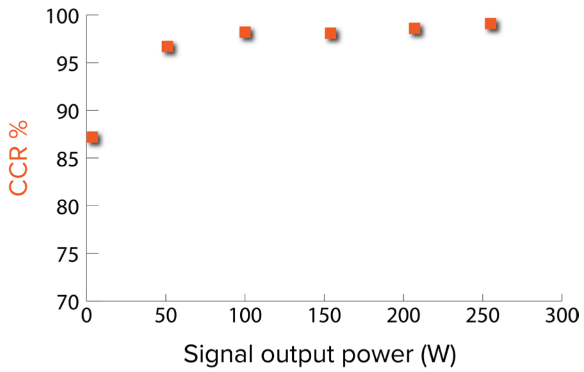

Figure 14: Example of CCR in relation to signal output power, measured for the aeroGAIN-ROD 3.1

Figure 15 shows the evolution of the MFD with signal output power. The MFD decreases with thermal load - the typical reduction is on the order of 0.1 %/W (signal output power).

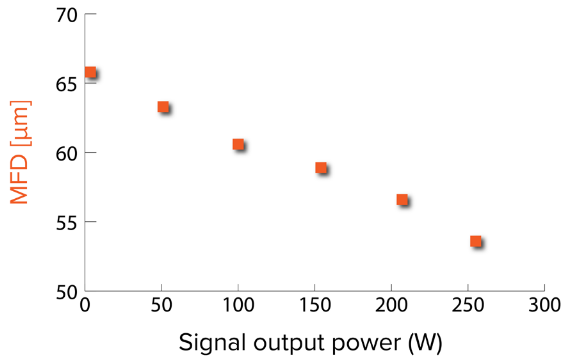

Figure 15: Example of MFD in relation to signal output power, measured for the aeroGAIN-ROD 3.1

Figure 16 shows a typical example of how the PER improves with signal output power. It is expected to obtain an active PER of ≥ 20 dB.

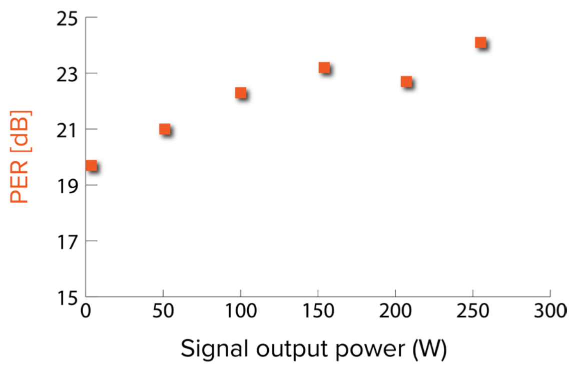

Figure 16: Example of PER in relation to signal output power, measured for the aeroGAIN-ROD 3.1

The beam quality of the ROD fiber is measured by sampling a fraction of the light to an M^2 setup. M^2, astigmatism and asymmetry values should be monitored. The measured M^2 value is highly dependent on the operating conditions. The M^2 value is expected to decrease as the signal output power increases. Under nominal operation at maximum recommended power a typical M^2 value is 1.05.

It is not sufficient to observe an M^2 value < 1.2-1.3 to ensure long term reliability. Good seed coupling is the key factor. Poor seed coupling will reduce the lifetime and trigger static mode deformation that will create irreversible damage to the ROD fiber.

See Figure 17 and Figure 18 for M^2 average, astigmatism and asymmetry of an aeroGAIN-ROD 3.1 as a function of signal output power. The set of data represents a typical distribution for this product.

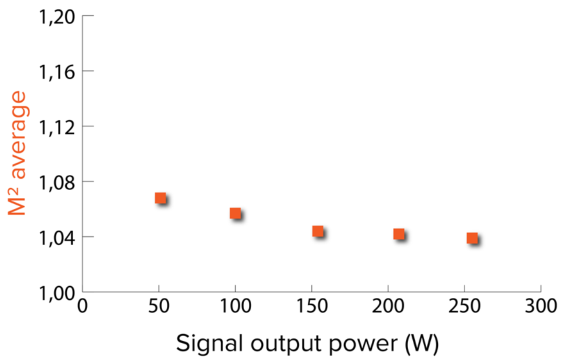

Figure 17: Example of M^2 average in relation to signal output power, measured for the aeroGAIN-ROD 3.1

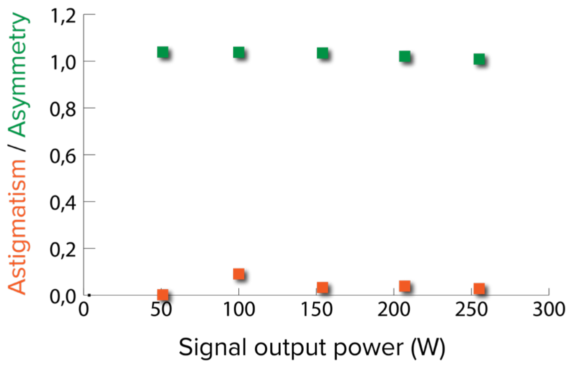

Figure 18: Example of astigmatism and asymmetry in relation to signal output power, measured for the aeroGAIN-ROD 3.1

It is recommended to monitor the signal output power, near field images, CCR, MFD, PER and M^2 of the output during operation to ensure that coupling is maintained.

RELIABILITY

The aeroGAIN-ROD is designed for robust performance with diffraction limited beam quality. To ensure reliable performance, aeroGAIN-RODs are tested at their recommended maximum signal average output power under nominal operation.

Figure 19 shows a typical signal average output power over 1000 hours of testing for the aeroGAIN-ROD-2.1, 3.1 and 3.2, with a 5 W seed level at ≈ 1030 nm, ≈ 20 ps pulse width, 20 MHz, 80 MHz, and 40 MHz repetition rate, respectively to ensure a peak power below 250 kW and ≈ 976 nm pumping.

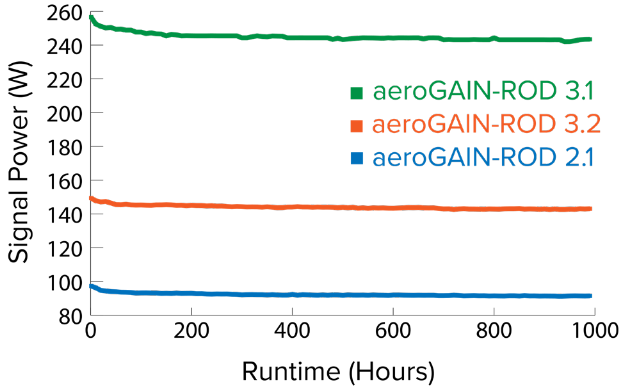

Figure 19: Example of measured signal average output power over 1000 hours of testing

A power decrease is typically observed within the first 10s-100s of hours. This decrease is highly dependent on the operating conditions. Hereafter, a slope of less than 1-3 W/1000hours is typically observed.

The aeroGAIN-RODs show excellent stability with very low degradation over several 1000s hours of testing. PER, CCR, MFD, beam profile and M^2 are maintained.

APPLICATION EXAMPLE

Additional information can be found in the following paper showing characterization and more than 4000 hours of operation of the aeroGAIN-ROD-3.1 used in a chirped-pulse-amplification configuration:

Pedersen, M.E.V., Johansen, M.M., Olesen, A.S., Michieletto, M., Gaponenko, M., and Maack, M.D. (2022) '175 W average power from a single-core rod fiber-based chirped-pulse-amplification system', Optics Letters Vol. 47, Issue 19, pp. 5172-5175 (2022).

Available at: https://doi.org/10.1364/OL.471631

SAFETY AND REGULATORY INFORMATION

Safety

This guide is for technical personnel involved in the selection, planning and deployment of lasers in laboratory and industrial settings. The guide assumes a reasonable knowledge level of lasers and photonic principles.

Do not adjust or remove the 2 water plugs, the 2 end fittings or the 8 screws holding the cover (doing so invalidates the warranty).

Cleaning endcaps

The aeroGAIN-ROD endcaps are clean upon delivery. However, they may collect impurities when handled. Inspect endcaps with an optical microscope. Small impurities may be removed by blowing filtered air or nitrogen on the end facets, or careful cleaning with lens paper wet in isopropyl alcohol.

It is important to use the necessary laser safety equipment when operating the aeroGAIN-ROD and the equipment associated with testing. We highly recommend using an interlock, that can monitor the signal average output power and shut down the pump and seed laser on a ms time level, if any irregularities are observed.

Environmental

RoHS: Directive 2011/65/EU and amendment 2015/863. On the restriction of the use of certain hazardous substances.

REACH: Directive EC/1907/2006 Registration and ‘Candidate List of Substances of Very High Concern’ published ECHA on or before January 23, 2024. Evaluation, Authorization and Restriction of Chemicals.

Quality Compliance

All NKT Photonics products are produced under our quality management system certified in accordance with ISO 9001:2015 and in some cases, also in accordance with ISO 13485:2016

Warranty

The unit is sealed with two labels “WARRANTY VOID IF SEAL IS BROKEN OR REMOVED”:

NKT Photonics strongly advise against breaking the seal, as doing so invalidates the warranty.

Service and Support

If you need help or have questions regarding the aeroGAIN-ROD, contact NKT Photonics through our support website at:

https://www.nktphotonics.com/support

NOTE: Before contacting NKT Photonics support, please read through this application note and prepare material demonstrating how the unit is not performing as expected.

Shipping information

For RMA purposes, ship the unit to the following address:

NKT Photonics A/S
Blokken 84
DK-3460 Birkerød
Denmark

Please include:

- Name
- Address
- Contact information
- RMA CAS-number

Do not ship the unit before an RMA number has been issued.