

## APP NOTE # 2.0

JULY 16

# COUPLING TO AEROGAIN-ROD FIBERS

This application note addresses how to couple signal and pump light to and from a simple reverse pumped amplifier based on an aeroGAIN-ROD fiber.

Suggestions for part numbers and specifications are given. The current version of the note does not cover optimization of fiber length, end-caps or amplifier parameters.

## Setup

The seed and pump coupling setups are illustrated in Figure 2 and Figure 3. In Figure 2 seed light is coupled from an aeroPULSE seed laser into the rod fiber through a free space optical isolator using a mode matched lens and mirrors for angular beam translation. A  $\lambda/2$ -plate is used for control of the seed polarization. In Figure 3 pump light is coupled from a delivery fiber into the ROD fiber in the backward direction using a set of high NA mode matched lenses. The signal light from the ROD fiber is extracted using a long wavelength pass filter or dichroic mirror.

## ROD fiber handling

The aeroGAIN-ROD is equipped with two 0° AR coated end-caps in order to avoid end facet damage and reflections, and should be handled with great care using gloves and making sure not to touch the end facets. The ROD fiber can also be delivered with one or two angled AR coated endcaps in order to have a further reduction in reflections. 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. Therefore, the ROD fiber is held in an 80cm long water-cooled aluminium holder with a V-groove and subsequently covered with a thin metal sheet for fixation and heat dissipation purposes. Furthermore, cooling of the aeroGAIN-ROD fiber may provide better performance as temperature is stabilized.

## Cleaning ROD fiber end facet

The aeroGAIN-ROD end facets are clean upon delivery from the manufacturer. However, they may collect impurities when handled, and can be inspected by 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. See for instance cleaning of optical surfaces in the Layertec catalog

(<https://www.layertec.de/en/downloads/index>).

## The aeroGAIN-ROD module

The aeroGAIN-ROD fibers can be delivered mounted as aeroGAIN-ROD modules ensuring easy and secure handling as well as easy mounting and coupling. Figure 1 shows a picture of the aeroGAIN-ROD module. This ready to use solution ensures ROD fiber mounting without any stress introduced 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. The module can be delivered with a ChromiAL TCP processed surface for industrial use by customer request. The aeroGAIN-ROD module has been severely tested with respect to climate change, vibration, and drop testing, and is very robust against transport and storage conditions. The module can tolerate large temperature changes from -30°C to 60°C and large vibrations, shock tested up to 1G at frequencies from 30Hz to 500Hz, without affecting the optical properties of the ROD fiber. Even when the module is packed for transportation it has been tested for drops of a few meters also without destroying the module or affecting the ROD fiber's optical properties. For specifications see the aeroGAIN-ROD module datasheet



Figure 1: Picture of the aeroGAIN-ROD module.

## Seed Coupling

### Lens selection

aeroGAIN-ROD fibers feature a signal core with a very low numerical aperture (NA) and good seed coupling is best obtained by using a lens with a long focal length and a small NA. Seed input end of the ROD is marked by the manufacturer. The collimating lens should be chosen for mode matching the seed with the aeroGAIN-ROD, e.g. by using the fiber collimation equation:

$$f = \frac{\pi D(MFD)}{4\lambda}$$

where  $f$  is the focal length,  $D$  is the diameter of the collimated beam between the two lenses, and  $MFD$  is the mode field diameter of the aeroGAIN-ROD.  $D$  should be smaller than the aperture of the isolator to avoid beam clipping. For example, using a collimated seed beam from an aeroPULSE with  $D \approx 1\text{ mm}$  the incoupling lens could be an *IR aspheres*  $f = 60\text{ mm}$  lens from *Light Path* (GPX25-60).

### Isolator

It is recommended that the seed system is protected with a faraday optical isolator optimized for the seed wavelength to avoid damage and instability, and matching the isolator to the extracted system power. For a polarization maintaining (PM) seed delivery fiber, use a polarization dependent isolator e.g. a *free space high power optical isolator pavos series* from Electro-Optics Technology.

### $\lambda/2$ plate

For PM operated aeroGAIN-ROD fibers it is recommended to use a  $\lambda/2$ -plate after the isolator to align the polarization. For non-PM operation the last  $\lambda/2$ -plate can be omitted. A suitable  $\lambda/2$ -plate could be e.g. *Thorlabs WPH05M-1030*.

### Translation stages

Ensure sufficient degrees of freedom to control the seed coupling, e.g. minimum two IR coated mirrors for the  $\theta\phi$ -control and xyz-control of the seed coupling lens. Avoid translating the aeroGAIN-ROD fiber itself during alignment.

### Residual pump light

Residual pump light can cause unwanted heating of optical components that may result in drift of alignment. Therefore it is recommended to use a pin hole beam block immediately before the rod and a short wavelength pass filter to reflect the 976 nm pump light to a beam dump, for instance a *Layertec* short wavelength pass filter (108881). The seed coupling lens holder should still be able to withstand a certain amount of heating from residual pump light.

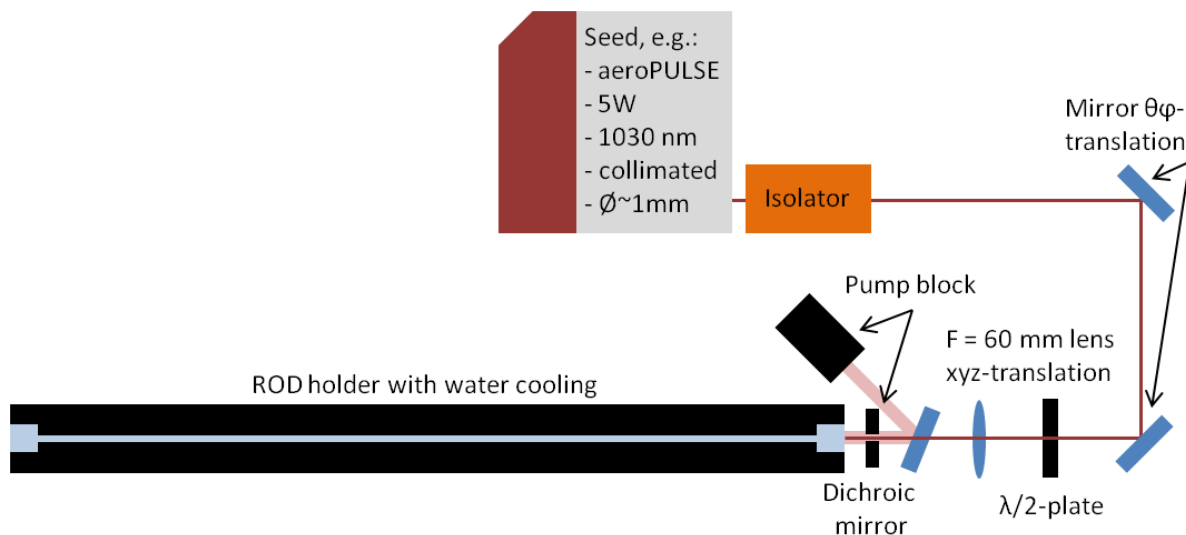


Figure 2: Setup for seed coupling, where the pump coupling is omitted, see Figure 3. The seed light is coupled from a PM single mode seed laser into the aeroGAIN-ROD fiber through a free space optical isolator using a set of mode matched lenses. A  $\lambda/2$ -plate is used for control of the seed polarization.

## Pump Coupling

### Lens selection

A pump coupling set of lenses with high NA should be used in order to couple high NA pump light from the delivery fiber into the aeroGAIN-ROD fiber. The fiber collimation equation can be used for mode matching. For a 200 $\mu\text{m}$  delivery fiber use e.g. an *Aspheric* lens  $f = 30\text{mm}$  (25-30-FPX-S-B) for pump collimation and an *Aspheric* lens  $f = 20\text{mm}$  (25-20-HPX-U-C) for pump coupling.

### Filter

To filter the signal output from the pump light use a long wavelength pass filter or a dichroic mirror to reflect the pump light and transmit the signal output, e.g. *Layertec HRs+p* (22.5°,820-990nm, 108834). Use a short wavelength pass filter for extra protection of the pump diodes, e.g. *Layertec HRs+p* (22.5°,1030nm).

### Translation stages

For pump coupling use a  $\theta\phi$ -stage for translation of the long wavelength pass filter and a xyz-stage for the pump coupling lens. In addition, the pump collimation lens holder should also have a z-translation to ensure proper collimation of the beam into the beam diagnostics setup (e.g. CCD camera or power meter).

## Coupling Procedure

**IMPORTANT:** Always turn on the seed signal and ensure good coupling before activating the pump lasers.

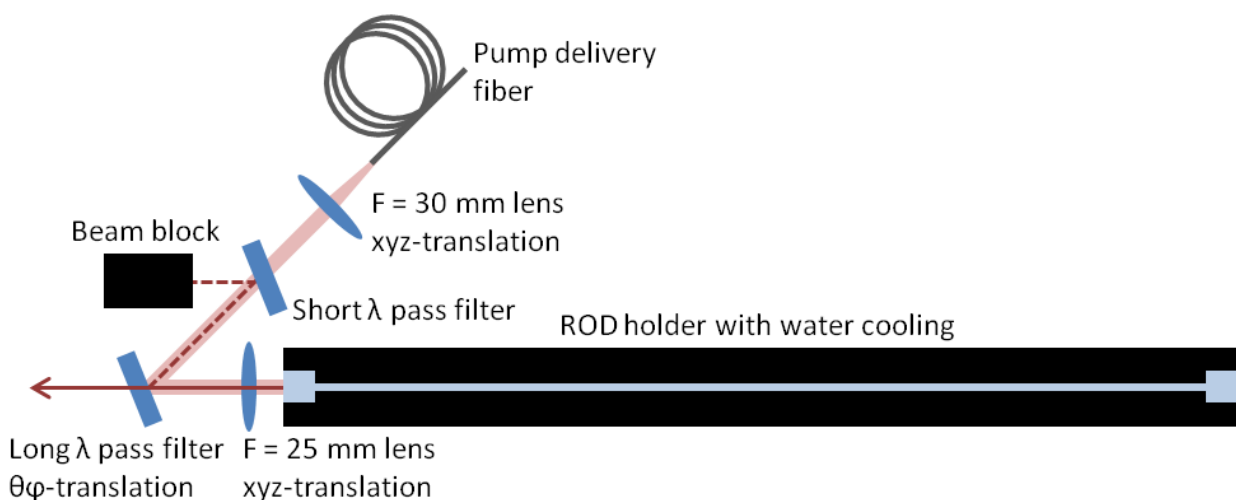


Figure 3: Setup for pump coupling. The pump light is coupled from a delivery fiber into the rod fiber in the backward direction using a set of high NA mode matched lenses. A dichroic mirror is used for extraction of the signal light.

A pumped and unseeded ROD fiber will store a lot of energy that will eventually be released as a spontaneous pulse. This can happen within seconds. These pulses have very high peak power, and can damage both fiber and other equipment.

### For PM and non-PM use

- Align the collimated seed light horizontally and along the anticipated path towards the aeroGAIN-ROD fiber using the two  $\theta\phi$ -stages.
- Place the aeroGAIN-ROD fiber in the holder.
- Insert the seed coupling lens.
- Optimize the seed coupling at low power by walking the beam for maximum core/clad ratio and Gaussian beam shape. Only use the  $\theta\phi$ -stages after the isolator.
- Use a CCD camera (e.g. Spiricon GRAS20) for optimum alignment. Use the xyz-stage holding the pump coupling lens to collimate and align the output beam towards the CCD camera.
- Collimate and align the pump light horizontally and along the anticipated path towards the aeroGAIN-ROD fiber using the  $\theta\phi$ -stage holding the long wavelength pass filter or dichroic mirror and the z-translation of the pump collimation lens.
- Couple approximately 10 W of pump light into the aeroGAIN-ROD fiber.
- Optimize coupling of the pump light using the  $\theta\phi$ -stage only.

### For PM use only

- Direct the output beam through a  $\lambda/2$ -plate, a polarizing beam splitter cube (PBS) and towards a power meter.
- Turn up the pump power to maximum level.
- Rotate the  $\lambda/2$ -plate before the PBS such that there is minimum power through the PBS.
- Minimize the power further by rotating the  $\lambda/2$ -plate before the seed coupling lens.
- Repeat the process iteratively until a global minimum is found.

### Safety

It is important to use the necessary laser safety equipment when operating the aeroGAIN-ROD-PM85 and the equipment associated with testing. Also, an interlock should be installed, 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.