Optoelectrode Technical Reference

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NeuroNexus

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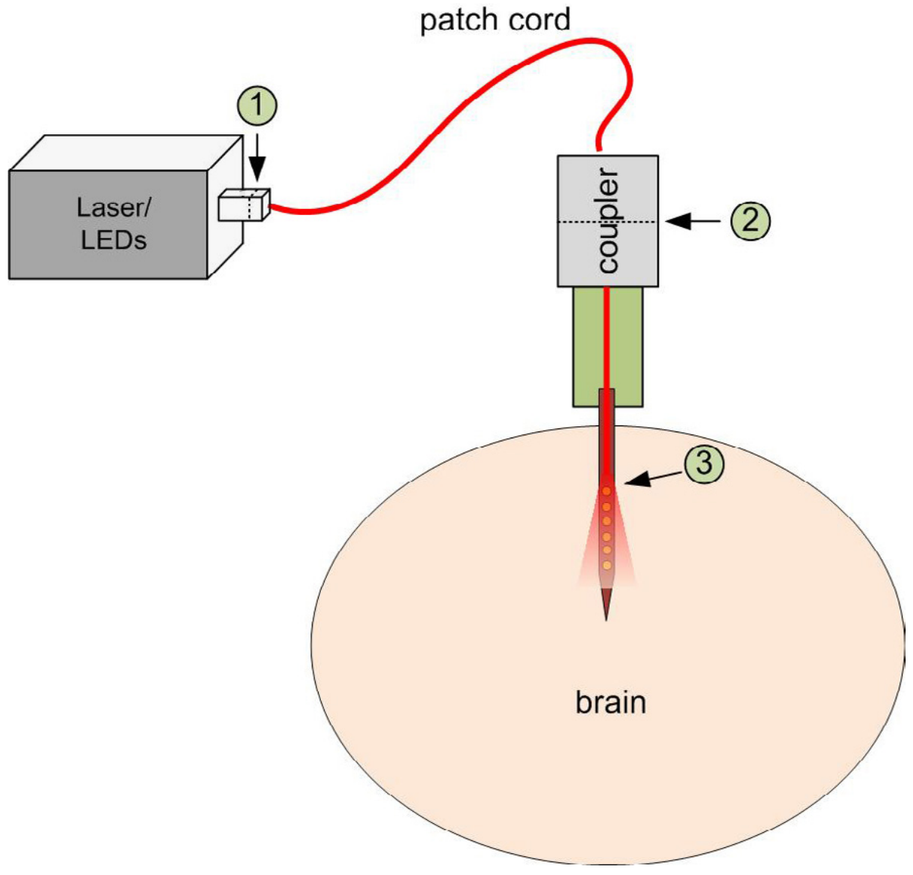
Optogenetics Optical System

The efficiency of light delivery is an important consideration for an optical system in optogenetics applications. There are several critical junctions in an optical system that can affect optical transmission. Losses can occur at:

1. **Light source/Patch cord interface**
2. **Patch cord/Optoelectrode interface**
3. **Optoelectrode/Tissue interface**

Every optoelectrode comes with a data sheet characterizing and reporting transmission efficiency (light source to probe connector). Because the tissue interface is biological, models are used to approximate coverage and efficiency.



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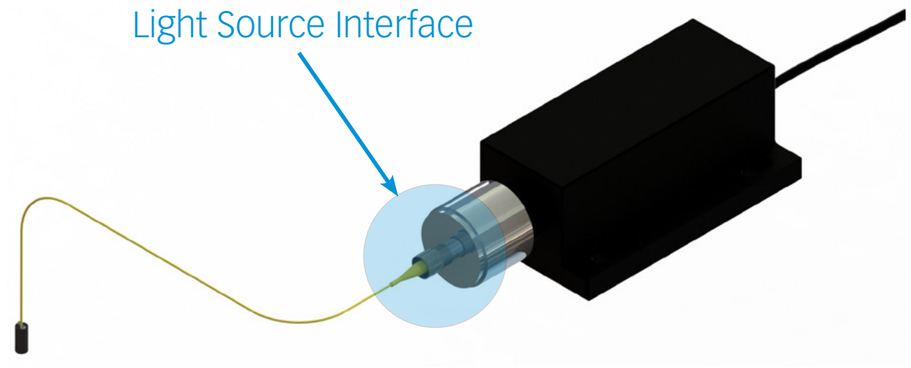
Light Sources

Light sources, typically lasers or LEDs for optogenetics applications, are coupled to a commercial optical connector (FC/PC, SMA, LC) to interface with other components of the optical path.

NeuroNexus recommends and provides LED lasers with FC/PC connectors.



Typical commercial connectors provide 70-90% transmission (-0.15 to -0.05 dB).

It is optimal to use a patch cord with core diameter that is equal to or larger than that of your light source. NeuroNexus currently offers patch cords with core diameters of 50 µm, 105 µm, or 200 µm.

Typically, laser sources can be coupled to small diameter cores (50 µm or less) with optimal efficiency (> 80%). LED sources require large diameter cores (e.g. 200 µm) for efficient coupling.

Patch Cords

There are three important considerations when ordering a NeuroNexus patch cord (right):

1. **Light source-end connector (LC, SMA, or FC/PC) (Fig. 1)**
2. **Probe-end connector (Ceramic Ferrule) (Fig.2)**
3. **Fiber core diameter**

NeuroNexus Patch Cord

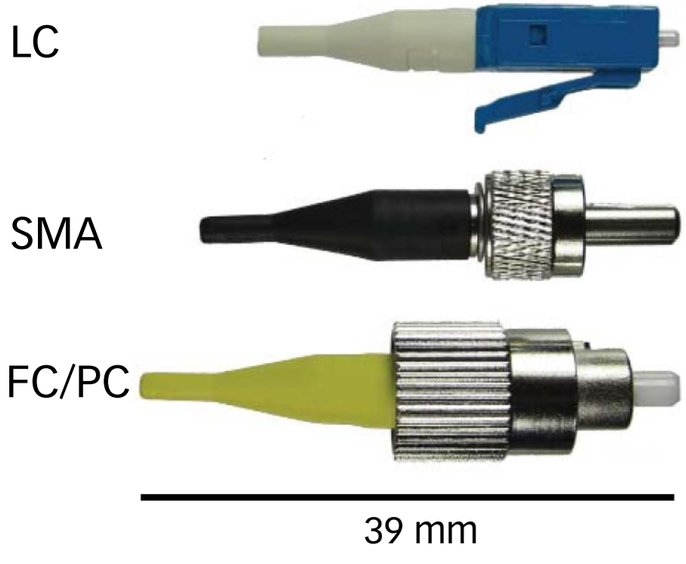


Figure 1: Light source-end connectors

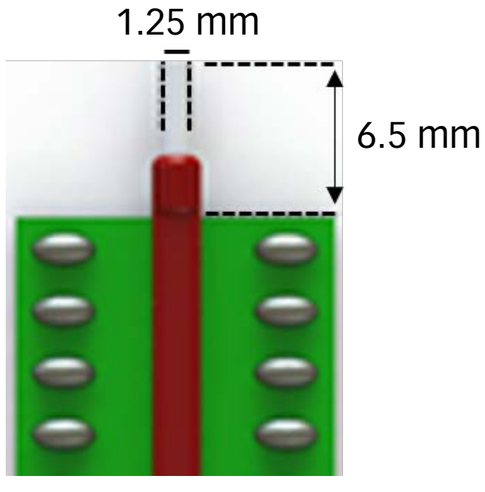


Figure 2: OALP Probe-end connector

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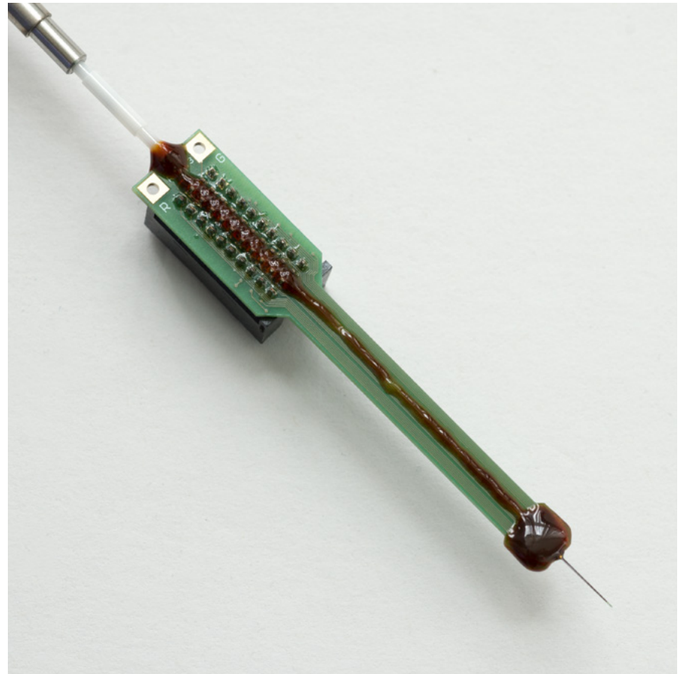
Optoelectrode - Ferrule (LP)

NeuroNexus offers ferrule-terminated Optoelectrodes.
The 1.25mm diameter ferrules are widely used in many optogenetics experiments.

The LP (Low Profile) line of Optoelectrodes are compatible with many existing optogenetics tools (such as patch cords) from other vendors.

Using a simple ferrule-to-ferrule connection aided by a ceramic sleeve, users can expect > 70% optical transmission from the patch cord to LP Optoelectrodes.

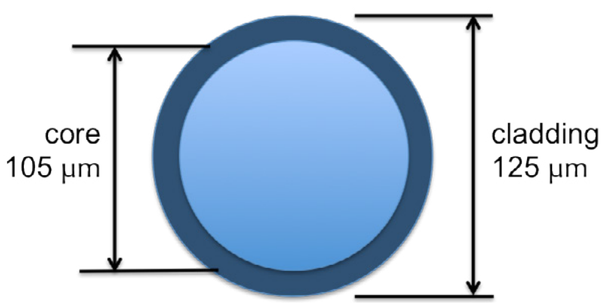
Because there is no latching mechanism, the optical connection is maintained only by the friction between the ferrules and the ceramic sleeve.



Fiber Specification

Standard NeuroNexus Optoelectrodes can be configured with the following fibers:

Fiber I.D.	Fiber O.D.	Numerical Aperture
50 µm	65 µm (etched)	0.22
105 µm	125 µm	0.22
200 µm	225 µm	0.22



- High numerical aperture fibers offer better compatibility with LED systems and higher angle of divergence through tissue, resulting in larger tissue volume stimulation
- Smaller diameter fibers result in less tissue damage

Tissue Optics

A commonly asked question relating to optoelectrodes is:
How deep does light travel in tissue?

There several key factors to consider:
- Core diameter (2 *r*)
- Numerical aperture (*NA*)
- Scattering coefficient (*S*)
- Refractive index of tissue (n_{tis})

Some equations to consider:

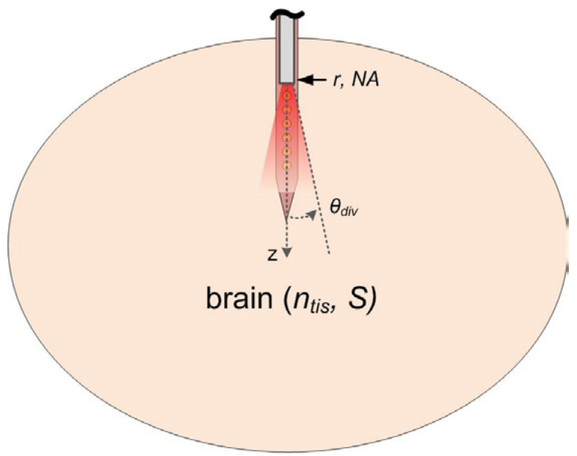
Intensity fraction due to geometric spreading

$$\frac{I(z)}{I(z=0)} = \frac{\rho^2}{(z+\rho)^2},\ \rho = r\sqrt{\left(\frac{n}{\mathrm{NA}}\right)^2 - 1}$$

Intensity fraction due to spreading and scattering

$$\frac{I(z)}{I(z=0)} = \frac{\rho^2}{(Sz+1)(z+\rho)^2}$$

Ref: Aravantis et al. 2007, JNE



A standard NNx optoelectrode has the following characteristics:
- Multimode
- Fused silica
- Buffer removed
- *NA* = 0.22
- *r* = 52.5 µm
- θ_{div} = 9.3°

Intensity Fraction with Spreading and Scattering

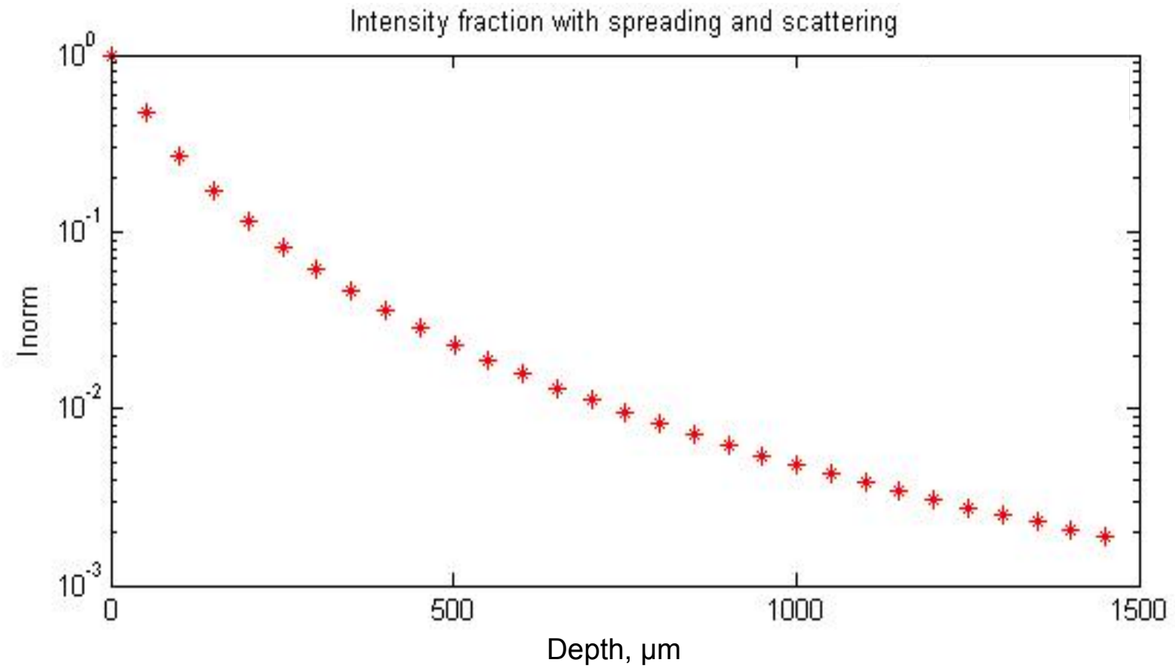


TABLE: Power Output Levels and Maximum Depth at 2mW/mm²

P_{tip} (mW)	I_{tip} (mW/mm²)	Depth at 2mW/mm²
1	115	625 µm
10	1155	1500 µm
40	4620	2500 µm

This plot was created with the following parameters:

NA = 0.22
θ_{div} = 9.3°
r = 52.5 µm
n_{tis} = 1.36
S = 11.2 mm^{-1}

$I_{fraction}$ = Normalized light fraction

Contact NeuroNexus for a free Matlab script for the shown plot

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Relationship between Intensity and Depth

To get a model for light intensity at depth for your configuration, multiply $I_{fraction}$ (from the "Intensity Fraction with Spreading and Scattering" graph on the previous page) by I_{tip}, where:

Intensity at the tip (I_{tip}) = Measured Power (P_{tip}) / Area of Core [mW/mm^2]

The maximum efficacy depth is determined by your application's intensity threshold, which is related to the efficiency of transfection (e.g. 2 mW/mm^2)

For example (refer to the table on the previous page),
If P_{tip} = 10 mW and fiber core = 105 µm diameter (for a NNx optoelectrode), then I_{tip} = 1,155 mW/mm^2.

At 1,500 µm the fraction of intensity (normalized value) is ~0.0018 (see graph on previous page),
and I_{tip} = 1,155 mW/mm^2.

Therefore, the intensity is 2 mW/mm^2 at this depth (1,500 µm).

How to measure light output?

If you do not have a way to measure light output (P_{tip}), consider getting a optical meter. It is a useful investment as it will help you troubleshoot and gauge the efficiency of the optoelectrode.

There are several commercial meters available for price ranging as low as $50. NeuroNexus uses the Thorlabs S140C in our setup.

To measure the output, simply connect the optoelectrode to your light system and use a manipulator to lower the electrode tip into the optical chamber of your meter. Remember to convert the unit to mW.

Thorlabs S140C

Handling, Use, and Reusability

- Remove the case from its shipping box. Never touch the electrode shank, which protrudes from the PCB. Carefully remove the probe from the sticky foam (we recommend “rolling” the probe onto its side, instead of tipping it forward). When removing chronic assemblies, be very careful to not tip the probe shank toward the bottom of the plastic case.
- Do not apply excessive force on the optical connector.
- Slowly connect the patch cord to probe.
- Minimize any un-necessary junctions and connections between the light source and the probe.
- Use alcohol solution, EtO, or UV for sterilization. (To clean the probe, use a protease/enzyme cleaner. Acetone is acceptable, but not recommended.)
- Carefully clean connector fiber face with provided cloth before use. Maintaining cleanliness at each connection terminal is critical for efficient light output!

Neural Recording and Optical Artifact

Users collecting spike recordings have mostly satisfactory results. Some users report that recordings in the LFP band may be dominated by photoelectrochemical phenomenon. Please keep the following in mind:

- Artifact observed in optoelectrode experiments mostly likely photoelectrochemical effect, first seen by A.E. Becquerel (1839) (ref. 1)
- Magnitude is a function of light intensity, pulse-width, metal, and ionic species (ref. 2), but can also be a function of surface roughness and site size
- While the LFP band may be affected by the artifact, the unit (spike) recording band, typically 300 – 5,000Hz, is largely unaffected

1. Han, X., et al., Informational lesions: optical perturbation of spike timing and neural synchrony via microbial opsin gene fusions. Front Mol Neurosci, 2009. 2: p. 12.
2. Honda, K., Dawn of the evolution of photoelectrochemistry. Journal of Photochemistry and Photobiology A: Chemistry, 2004. 166(1-3): p. 63-68.

O-Series Technical Specifications

Transmission	> 70%
Durability	< 5% transmission variability after 40 connections
Rotation Test	< 2% variation during a single rotation
Connection Strength	> 300 g before latch separation, typical
Max. Shear Force	900 g (applied to top of female coupler)
Fiber Location	Terminated 200 µm above proximal site, unless specified. Tolerance ±50 % site spacing distance
Reference Site	Dependent on electrode design

References and Resources

- Deisseroth, K., et al., Next-generation optical technologies for illuminating genetically targeted brain circuits. J Neurosci, 2006. 26(41): p. 10380-6.
- Aravanis, A.M., et al., An optical neural interface: in vivo control of rodent motor cortex with integrated fiberoptic and optogenetic technology. J Neural Eng, 2007. 4(3): p. S143-56.
- Gradinaru, V., et al., Targeting and readout strategies for fast optical neural control in vitro and in vivo. J Neurosci, 2007. 27(52): p. 14231-8.
- Honda, K., Dawn of the evolution of photoelectrochemistry. Journal of Photochemistry and Photobiology A: Chemistry, 2004. 166(1-3): p. 63-68.
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http://www.openoptogenetics.org
http://www.stanford.edu/group/dlab/optogenetics/ (from Deisseroth group)
http://syntheticneurobiology.org/ (from Boyden group)