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Optoelectrode Technical Reference
Updated Aug 18, 2011

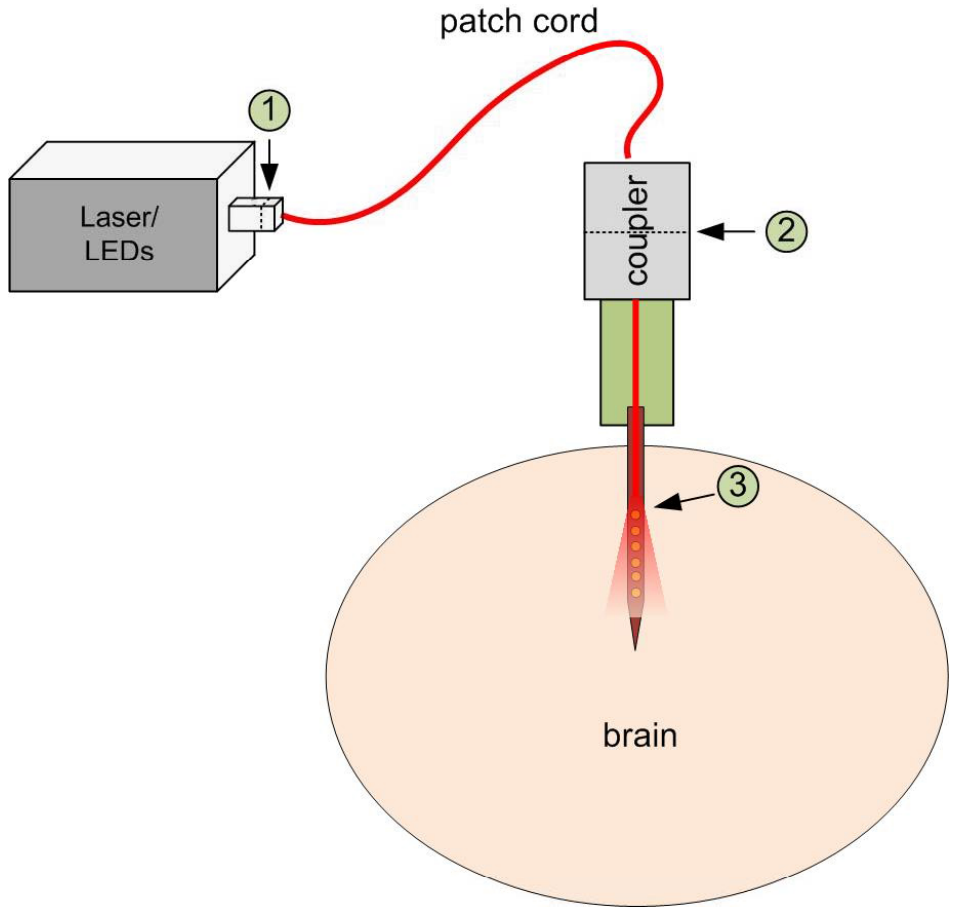
Coupling Efficiency

The efficiency of light delivery is an important consideration for any optoelectrode. There are several junctions in an optical system that could result in reduced optical transmission. It is useful to recognize that losses occur at:

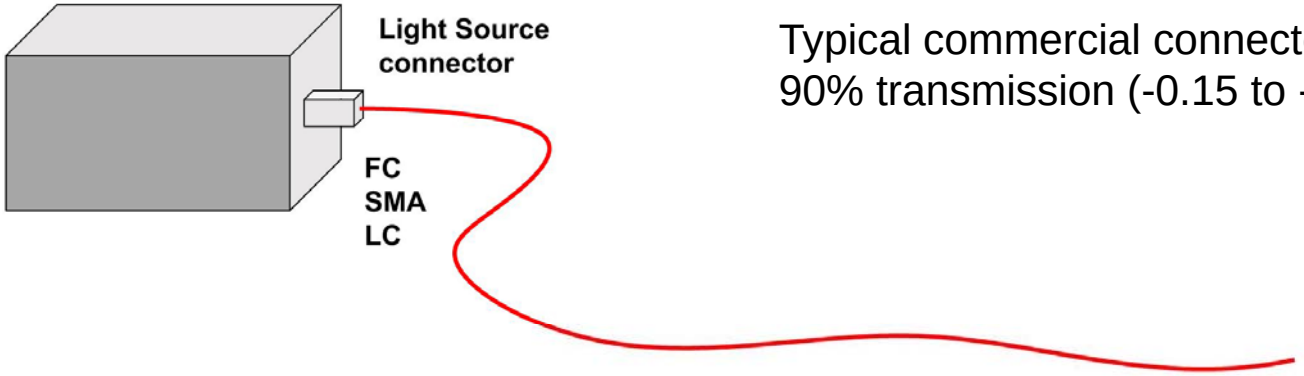
1. Light source connector
2. Probe connector
3. Tissue interface

Transmission efficiency through the probes (Light source to probe connector) is characterized and reported in each optoelectrode data sheet. Tissue interface is biological and there are models available to approximate its coverage and efficiency.

We will discuss each interface…



Light Source Connector



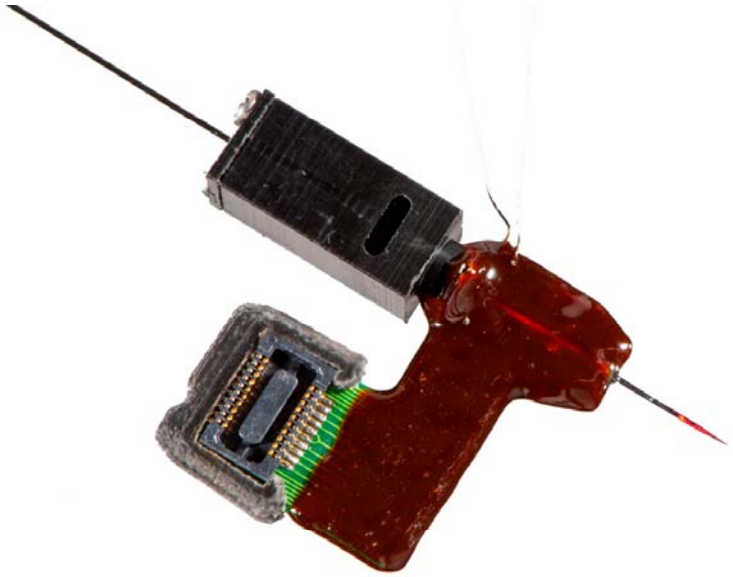
Typical commercial connectors provide 70-90% transmission (-0.15 to -0.05 dB)

NeuroNexus provide 3 commercial options (FC, SMA, LC) to interface with your light source.

It is optimal to use a patch cord with core diameter that is equal to or larger than that of your light source. Additionally, core diameter size mismatch to be minimized. NeuroNexus currently offers patch cords with core diameter of 50 µm or 105 µm. Be sure to check the core size of the patch cord from the specification sheet provided.

Typically, single mode laser sources have core size less than 10 µm and you may expect excellent efficiency. Alternatively, LED sources tend to have large diameter cores (e.g. 200 µm) and would result in lower efficiency.

Probe Connector - NeuroNexus Coupler (NNC)



NNC is in-house developed connector system. Its output specification is well understood and characterized. You will find a detailed transmission report for every O-Series Optoelectrode.

Brief NNC Specification

- Power transmission > 80% relative to patch cord output
- Variation < 2% during rotation
- Durability, < 5% decrease after 40 connections
- Connector can withstand shear force > 900g
- Latching secure up to 300g

Do you know you can now purchase NNC electrode with fiber only option from us?

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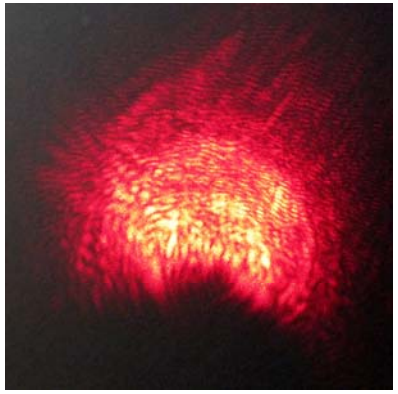
Optoelectrode Data Sheet

All NeuroNexus optoelectrodes are tested for the following:

- Visual inspection
- Optical transmission
- 1kHz impedance



Visual inspection: Accepted pattern. Tight multi-modal shape, probe creates shadow on bottom

Optical transmission data reports the overall transmission efficiency of a generic optical system (from light source through NNC patch cord and to each optoelectrode). Our test is based on the following setup:

- Test signal: 635 nm laser (406 nm produce similar result but is not reported)
- Light source with a 50 µm core fiber terminated in FC connector.

Note

- NNC coupler has a transmission efficiency (> 80%)
- NNC patch cord to light source coupling efficiency is > 80% if the core diameter of the source is <= 50um
- Your transmission measurement might be different than reported if you have light source with different configurations (e.g. core diameter, connector, etc).

Device	Probe ID	λ, nm	[1]Pout, mW	Pin, mW	Transmission
PC105		635	0.557	0.6	**92.8%**
PC106/DF21	1CB1	406	0.072	0.083	**86.7%**
PC106/DF21	1CB1	635	0.52	0.575	**90.4%**

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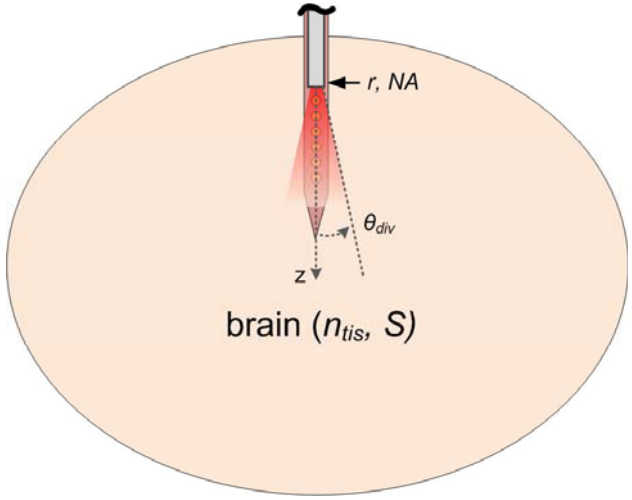
Tissue Coupling

A commonly asked question relating to optoelectrode 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:

$$\theta_{\text{div}} = \sin^{-1}\left(\frac{\text{NA}_{\text{fib}}}{n_{\text{tis}}}\right)$$

Intensity fraction due to geometric spreading

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

Intensity fraction due to spreading and scattering

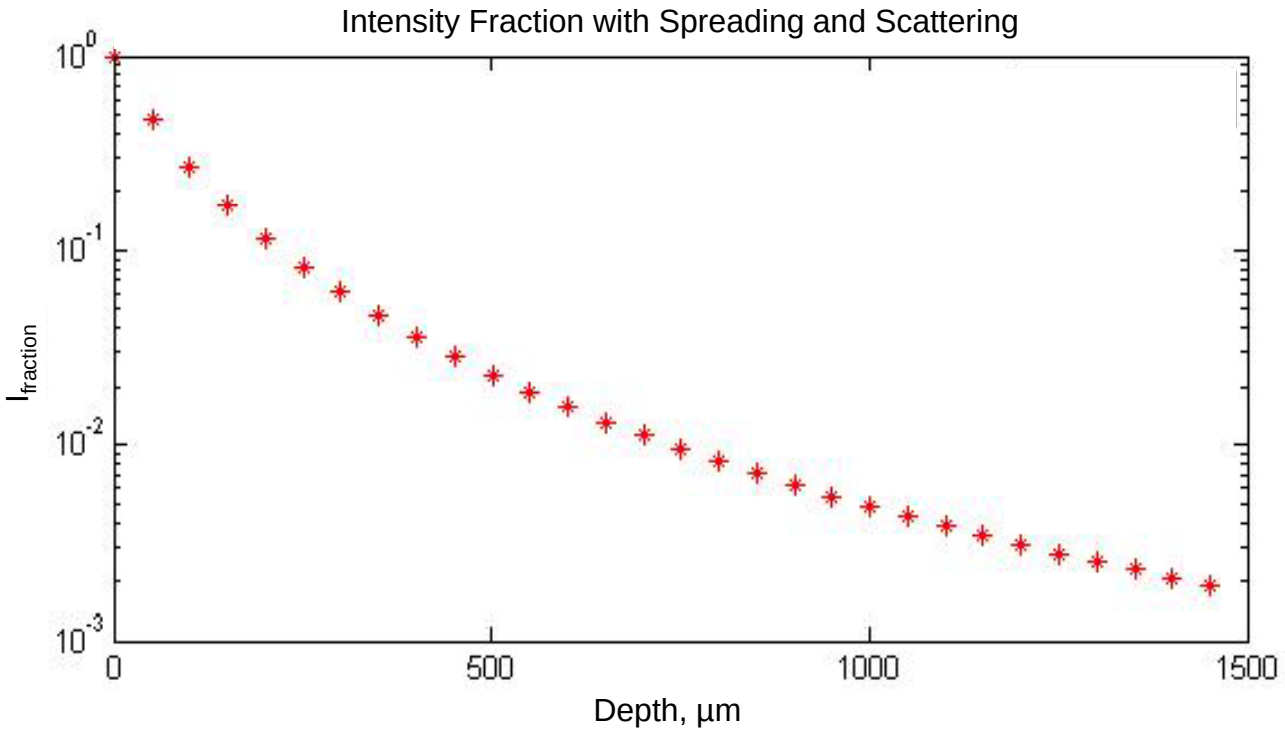
$$\frac{I(z)}{I(z=0)} = \frac{\rho^2}{(Sz+1)(z+\rho)^2}$$

A standard NNx optoelectrode has the following characteristics

- Multimode
- Fused silica
- Buffer removed
- ***NA*** = 0.22
- ***r*** = 52.5 µm
- $\boldsymbol{\theta_{div}}$ = 9.3°

Ref: *Aravantis et al. 2007, JNE*

Intensity Fraction with Spreading and Scattering



Plot Created with following Parameter

- ***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 above plot

Table: power output levels and maximum depth at 2mW/mm²

P_{tip}, mW	I_{tip}, mW/mm²	Depth @ 2mW/mm² *
1	115	625 µm
10	1155	1500 µm
40	4620	2500 µm

Relationship between Intensity vs Depth

To get a model for light intensity at depth profile for your system/configuration, multiple $I_{fraction}$ from chart “Intensity Fraction with Spreading and Scattering” on page 6 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. 2mW/mm^2)

For example (refer to the table on page 6),

If P_{tip} = 10 mW, 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 chart on page 6) and I_{tip} = 1,155 mW/mm^2.

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

How to measure light output?

If you do not have a mean to measure light output (P_{tip}) , you should consider getting a optical meter. It would be an 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 Thorlabs S140C in our setup.

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

Thorlabs S140C

Handling, Use & Reusability

- Carefully remove the optoelectrode from its shipping box. Never touch the electrode shank that is hanging off the PCB/connector package. Carefully remove the probe from the sticky foam. When removing chronic assemblies, be very care and not tipping the probe shank toward the bottom of the plastic case.
- Do not apply excessive force on optical connector
- For acute optoelectrodes, avoid applying excessive force on the fiber embedded in silicone, as this could cause a break within the silicone.
- Slowly connect patch cord to probe. To release the probe, rotate the connector and pull.
- Minimize any un-necessary junctions and connections between the light source and the O-Series probe.
- Use alcohol solution, EtO, or UV for sterilization
  - For this version of the optoelectrode, use of protease/enzyme cleaner is acceptable
  - Acetone is acceptable, however 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 & Potential Artifact

Generally, users who wish to collect spiking recording have mostly satisfactory results. Some users have reported that recordings in **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 also seen to be a function of surface roughness and site size
- Bandwidth of artifact is usually ~0.5 to 10 Hz, affecting LFP recording, but also observed in some single unit filters

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.

Artifact Solutions and Work Around

Artifact subtraction

Most customers capture the pulse events and subtract the artifact using a pre-measured average. Artifact average must be defined for each channel. Contact NeuroNexus for a starter Matlab script.

Filtering*

Single unit bandpass (typically 300-5000Hz) greatly attenuates artifact in most cases; NeuroNexus is working to understand exceptions

Surface Modification*

NeuroNexus is currently testing affects of surface modification. Contact us for beta testing.

Reflector (*In development*)

Using a small profile reflector to divert light from direct exposure on sites. Contact us for beta testing.

* Based on result from in vitro experiment; animal testing required; application dependent

Custom Offerings & Future Directions

Customization Options

- Unique fiber tip position +/-200 µm
- Fiber attachment on multi-shank probes (50 µm probes only)
- Plenum on patch cord for greater durability

Future Directions

- MEMS based optical reflector
- Smaller optoelectrode packages
- Sharpened tips, smaller fiber
- SBIR to develop modular, customizable thin-film waveguides
  - 30 x 70 µm cross-section
  - lateral light projection
  - customizable light port placement
  - mitigate or eliminate Becquerel artifact

Contact us for collaborations!

O-Series Technical Specifications Reviewed

Transmission	> 80%
Durability	< 5% transmission variability after 40 connections
Rotation Test	< 2% variation during a single rotation
Connection Strength	> 300g before latch separation, typical
Maximum Shear Force	900g (applied to top of female coupler)
Fiber Location	Terminated at 200µm above most proximal site, unless specified. Tolerance +/-± 200µm .
Reference Site	Not available in all O-series package

References & 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.
- 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.

- http://www.openoptogenetics.org
- http://www.stanford.edu/group/dlab/optogenetics/ (from Deisseroth group)
- http://syntheticneurobiology.org/ (from Boyden group)