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SU-8 Based Waveguide for Optrodes †

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Abstract: Neural probes can be equipped with light for optogenetics applications. Different approaches are used for delivering light to the tissue: an optical fiber coupled to the probe, a µLED or a waveguide integrated on the probe. Small probe dimensions, adequate optical power for photostimulation and good tissue penetration for in-vivo experiments are critical requirements. Thus, integrating a waveguide is a promising solution. This work shows the design and simulation of a SU-8 based waveguide for integration in a neural probe. The waveguide contains 3 apertures, spaced by 0.5 mm, which will allow the photostimulation of different brain regions simultaneously.

Keywords: neural probe; optogenetics; waveguide

1. Introduction

In neuroscience, the study of the function and behavior of the central nervous system is done using implantable electrodes [1]. Emerged from neuroscience, optogenetics uses opsins which are introduced in target neuron cells, to produce a biological effect on those cells when they are exposed to light, with high temporal and spatial accuracy [2,3]. For example, *channelrhodopsin-2* (*ChR2*) is a cation channel opsin that is directly activated by blue light, promoting cells depolarization [2]. A threshold of 1 mW/mm^2 for optogenetic activation is used as a reference [4].

An optogenetic implantable neural probe (optrode) can deliver light to the tissue through a waveguide [5,6], which presents several advantages over the use of optical fibers and µLEDs, such as: minimizes tissue damage during in-vivo experiments, ensures the optical power required for optogenetics activation and improves the control of the distance between stimulation and recording sites in the neural probe.

This work presents the design and simulation of a SU-8 based waveguide for integration on a neural probe with several recording sites. The waveguide is composed by SU-8 core and PMMA cladding and contains 3 apertures or light outputs, spaced by 0.5 mm. Thus, the neural probe will allow the photostimulation of different brain regions simultaneously.

2. Materials and Methods

Figure 1 shows an overall schematic of the neural probe integrating the waveguide and several recording sites. Figure 2 shows the simulated waveguide on *Zemax®* software and Table 1 shows the parameters used to implement the waveguide. The core layer is SU-8 ($n = 1.61$ at 450 nm) and the cladding layer is PMMA ($n = 1.50$ at 450 nm). An Al layer ($n = 0.62$ at 450 nm) was placed at the bottom

and the end of the waveguide, featuring the increase of the amount of light that exits the waveguide apertures.
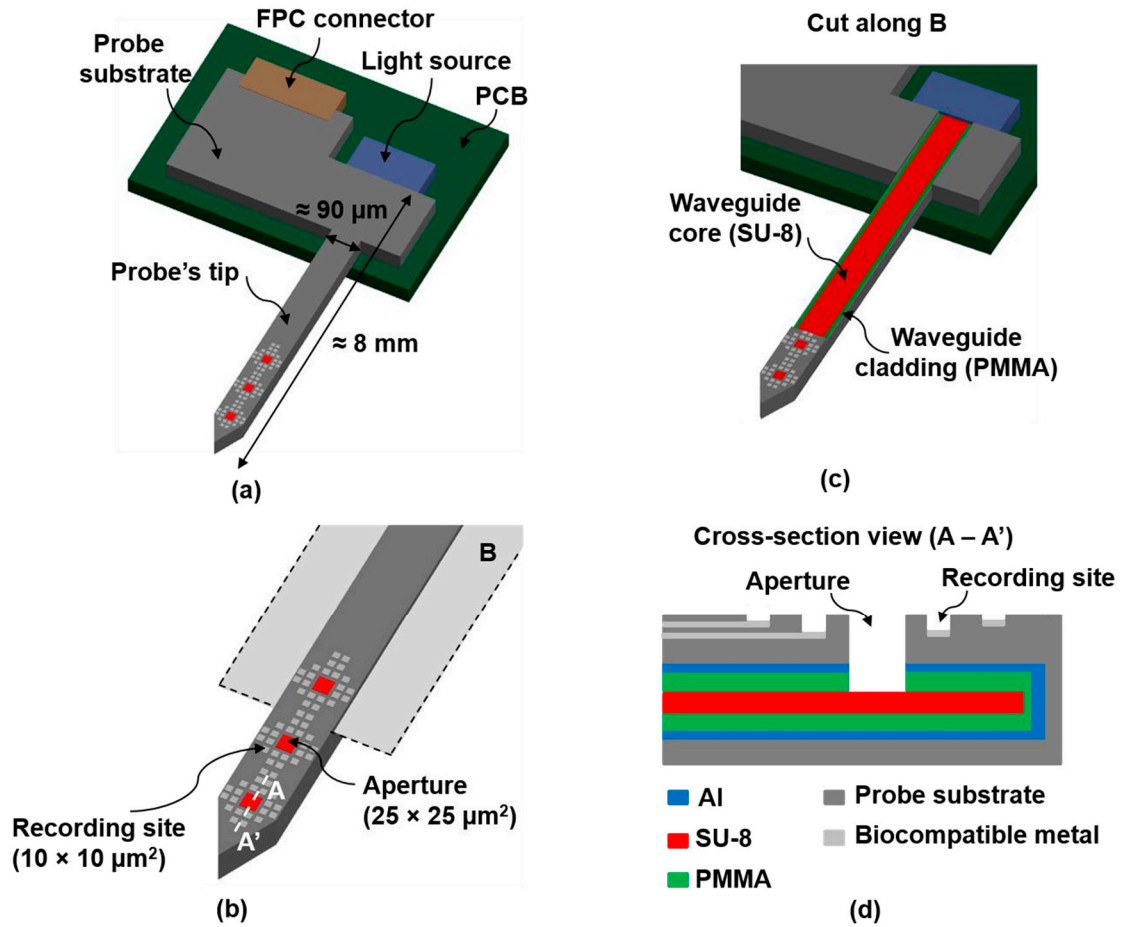

Figure 1. (**a**) Overall schematic of the final optrode; (**b**) Zoomed figure showing the probe's tip with several recording sites and 3 apertures or light outputs; (**c**) Cut along B (as indicated on (**b**)), showing the SU-8 based waveguide; (**d**) Cross-section view (A − A'), as indicated on (**b**).
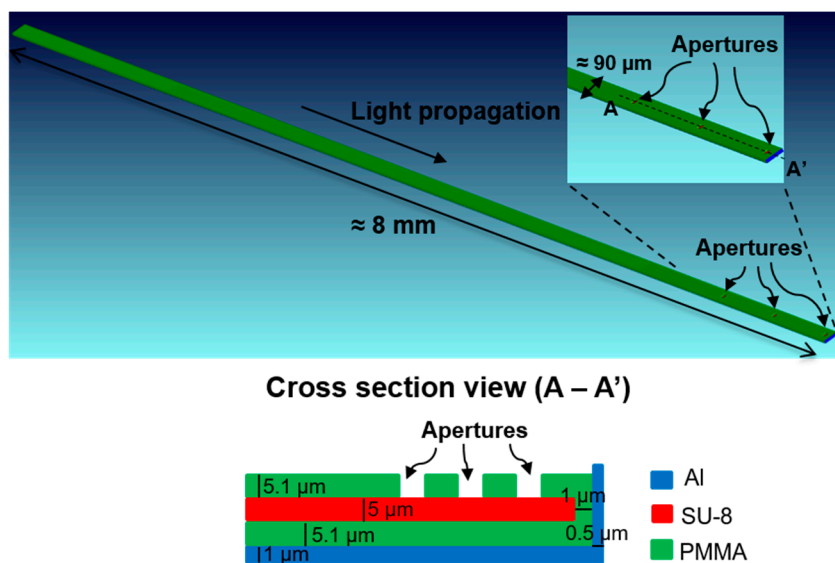

Figure 2. Geometry of the simulated waveguide.

Table 1. Parameters used for implementation of the SU-8 based waveguide (*Zemax*® units—millimeters).

Object Type	X Position	Y Position	Z Position	Material	X1/X2 Half Width	Y1/Y2 Half Width	Z Length
Rectangular volume	0	0	0.1	Al	0.0465	0.0005	8.0015
Rectangular volume	0	0.00305	0.1	PMMA	0.046	0.00255	8.001
Rectangular volume	0	0.00810	0.1	SU-8	0.045	0.0025	8
Rectangular volume	0	0.01315	0.1	PMMA	0.045	0.00255	6.935
Rectangular volume	0	0.01315	7.06	PMMA	0.045	0.00255	0.475
Rectangular Volume	0	0.01315	7.56	PMMA	0.045	0.00255	0.475
Rectangular Volume	0	0.01315	8.06	PMMA	0.045	0.00255	0.04
Rectangular Volume	−0.02875	0.01315	7.035	PMMA	0.01625	0.00255	0.025
Rectangular volume	0.02875	0.01315	7.035	PMMA	0.01625	0.00255	0.025
Rectangular volume	−0.02875	0.01315	7.535	PMMA	0.01625	0.00255	0.025
Rectangular volume	0.02875	0.01315	7.535	PMMA	0.01625	0.00255	0.025
Rectangular volume	−0.02875	0.01315	8.035	PMMA	0.01625	0.00255	0.025
Rectangular volume	0.02875	0.01315	8.035	PMMA	0.01625	0.00255	0.025
Rectangular volume	0	0.01065	8.1	PMMA	0.046	0.00505	0.001
Rectangular volume	−0.0455	0.01065	0.1	PMMA	0.0005	0.00505	8
Rectangular volume	0.0455	0.01065	0.1	PMMA	0.0005	0.00505	8
Rectangular volume	0	0.0086	8.101	Al	0.0465	0.00810	0.0005

For waveguide optical simulation on *Zemax*® software (at 450 nm), a light source with 1.6 W total power and 3 detectors on the top of each aperture were used. Table 2 shows the parameters used for the light source and Table 3 the parameters used for the 3 detectors. Incoherent irradiance was analyzed for each detector.

Table 2. Parameters used for the light source (*Zemax*® units—millimeters).

Object Type	X Position	Y Position	Z Position	Layout Rays	Analysis Rays	Power (W)	Cone Angle (°)
Source point	0	0.00810	0.1	1000	100,000	1.6	20

Table 3. Parameters used for the 3 detectors (*Zemax*® units—millimeters).

Object Type	X Position	Y Position	Z Position	Tilt about X (°)	Material	X Half Width	Y Half Width	X Pixels	Y Pixels
Detector Rect	0	0.016	7.0475	90	Absorb	0.013	0.013	100	100
Detector Rect	0	0.016	7.5475	90	Absorb	0.013	0.013	100	100
Detector Rect	0	0.016	8.0475	90	Absorb	0.013	0.013	100	100

3. Results and Discussion

The mean total power and the mean peak irradiance (after three iterations) for each detector are presented on Table 4. The obtained results meet the optogenetics requirements (>1 mW/mm²). Important future guidelines include the validation of this design, by evaluating the experimental performance of the waveguide (after neural probe fabrication) and its coupling to the light source.

Table 4. Simulation results.

Detector	Z Position (mm)	Mean Total Power (W)	Mean Peak Irradiance (W/mm²)
1	7.0475	3.27×10^{-3}	3.85×10^{2}
2	7.5475	2.95×10^{-3}	3.19×10^{2}
3	8.0475	2.65×10^{-3}	3.02×10^{2}

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