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Neuron Mid-Infrared Absorption Study for Direct Optical Excitation of Neurons

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Abstract

Neuron optical excitations are important for brain-circuitry explorations and sensory-neuron-stimulation applications. To optimize the stimulation, we identify neuron mid-IR absorption peaks in this study and discuss their meanings and delivery methods of mid-IR photons.

I. Introduction

Neuron optical excitation can provide non-contacting tools to explore brain circuitry and durable stimulation interface for regulating heart beats and visual as well as auditory sensory neuron stimulation. Laser inhibition and stimulation of neurons have been reported previously and visible or UV photons were directly used in earlier works [1, 2]. Recent techniques like binding photosensitive molecules to assist the excitation [3] and using genetically alter cells [4] to depolarize the neuron and evoke action potentials were also included for neuron stimulation. However, these approaches either involve photochemical reactions that cause cell damage/death or they are not yet practical for real-life applications due to the procedure of introducing foreign materials into human bodies.

II. Mid-Infrared and Near- Infrared Lasers Excitations

Recent studies have shown that it will be much safer to excite neurons through a thermal process by using heat to open the nerve cell's ion exchange channels and evoke action potentials [5, 6]. They found that the wavelength selection is critical and choosing long wavelengths at 1.45–1.54 μm and near 2μm range are easier to depolarize the cell.

With the recent development of high-power mid-IR (MIR) semiconductor lasers including quantum cascade lasers (QCLs) [7], interband cascade lasers (ICLs) [8], and Sb based interband lasers [9], the available MIR lasers can cover wavelength all the way from 2 to 20μm. Selecting right excitation wavelengths can effectively stimulate neurons with least peak power and pulse energy. Portable and battery supported optical stimulation units can then be developed for applications like heart-beat pace makers, visual and auditory neuron excitations for aging patients with degenerated sensing capability.

III. Experiments

To obtain accurate absorption spectrum of living neurons, we have to scan neuron transmission spectral when they are in serum-containing cell culture medium and normalize it by subtracting out the absorption spectrum of the medium alone, with the same optical setup. To achieve that we use GaAs wafers for the windows of the serum and neuron containing chambers. The container structure is shown in Fig. 1(a). We have tried to use silicon and considered other MIR window materials. The MIR transmission spectrum of silicon is not flat and transmission is lower. Other windows are either water resolvable or

not bio-compatible. GaAs wafer with a thin oxide coating has the best result up to near 18 μm wavelength as shown in Fig.1 (b).

The normalized absorption spectrum of cultured rat neurons (PC12 cell line) is shown in Fig. 2. As shown in the spectrum the main neuron absorption peaks are close to 3000nm and 6000nm. In the 1400–2500nm region there is a smaller absorption peak near 1450nm. This result is consistent with the fact that neuron cells contain a large percentage of water. That means it will be difficult to isolate the heating process when neurons are surrounded by aqueous medium. In fact, optical excitation can be absorbed by nearby water molecules and evoke action potential. However, the spatial resolution of such kind of neuron stimulation is low and it requires high pulse energy. The stimulation threshold and damage threshold difference will be reduced and that makes operations more dangerous. Furthermore, with larger amount of mass heating up, the cooling time becomes longer and that will force us to reduce laser pulse repetition rate. So, to deliver MIR photons to the excitation site, MIR fiber, like Chalcogenide fibers have to be used.

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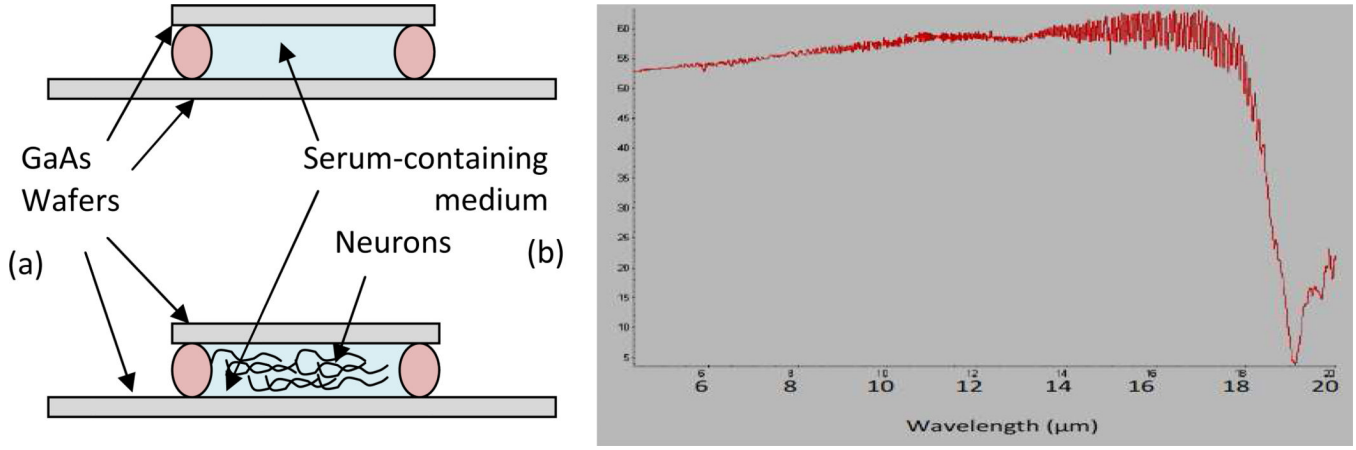

Fig. 1.

(a) Serum and neuron containers built by using GaAs wafers and rubber sealing gasket. (b) The MIR transmission spectrum of GaAs wafer.

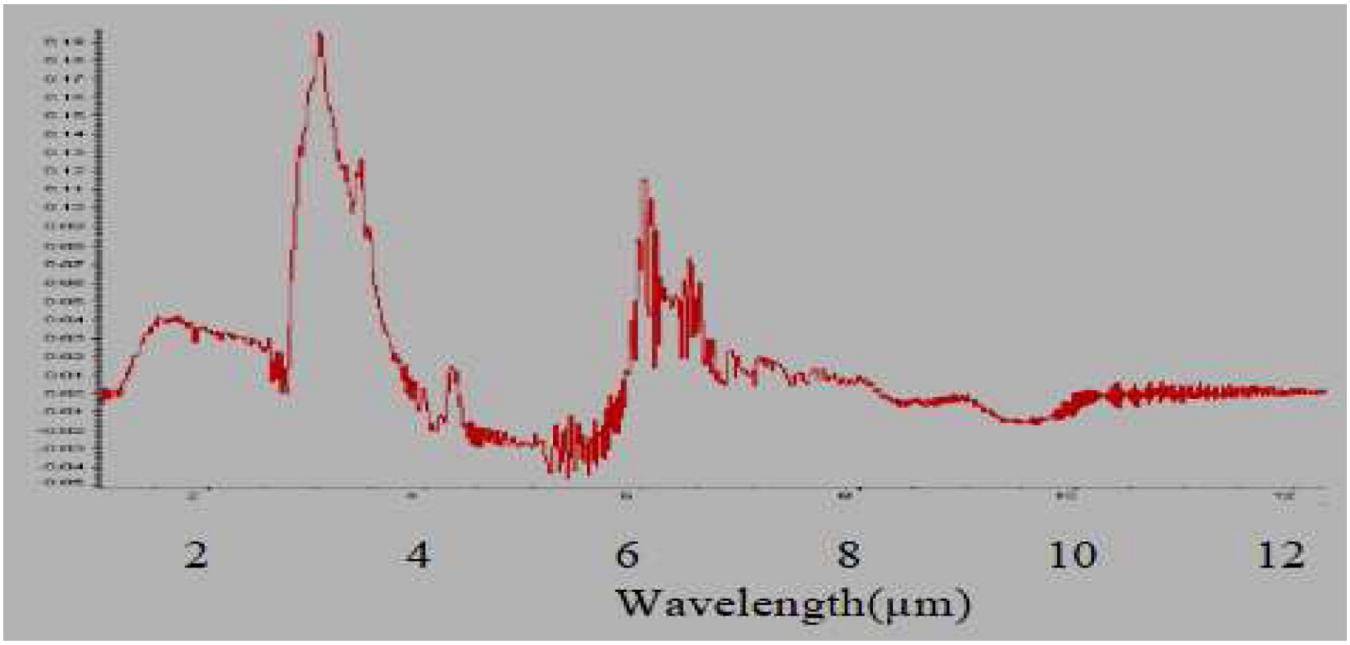

Fig. 2.
Cultured rat neuron MIR absorption spectrum.