Visual prosthesis based on Silicon PhotoMultipliers: the SPEye project

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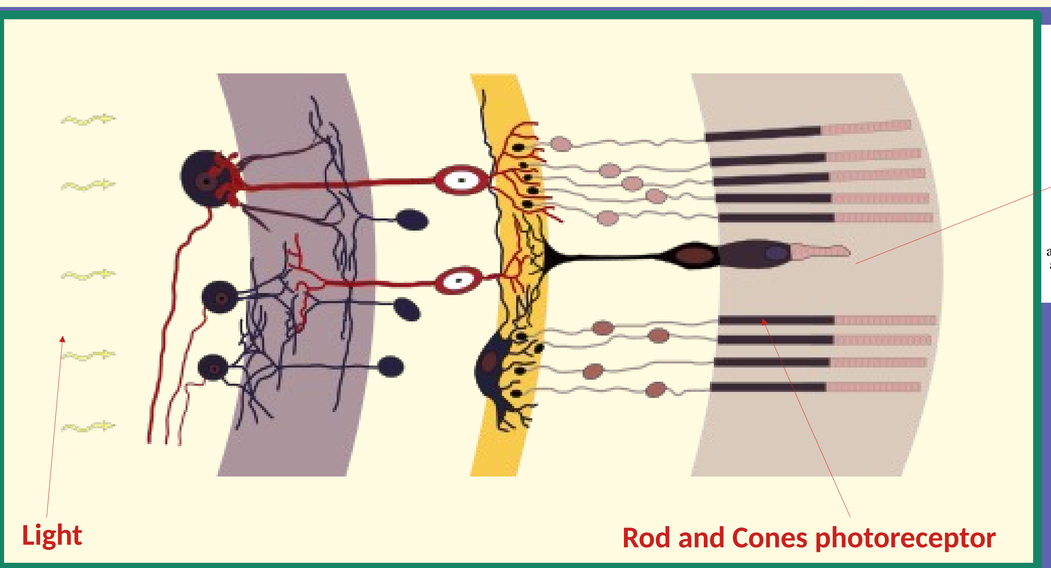
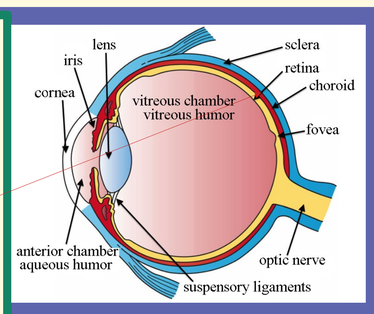
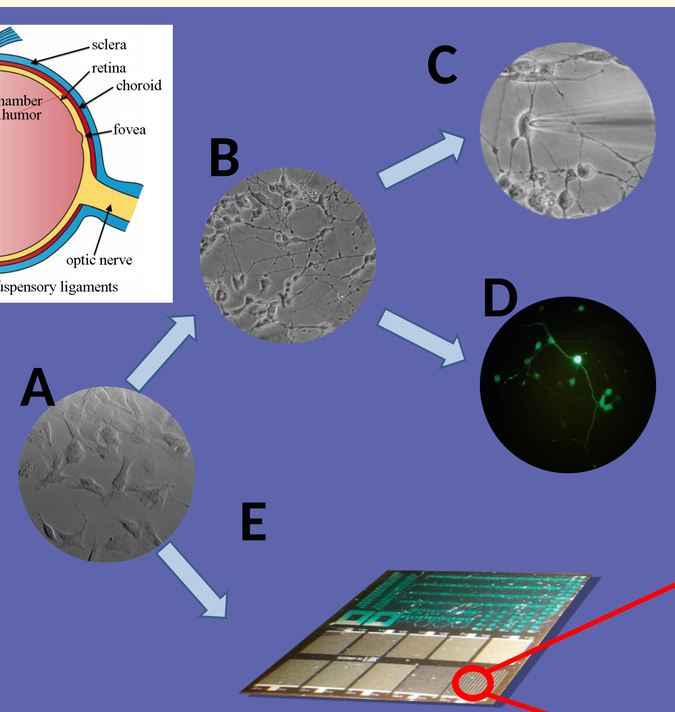
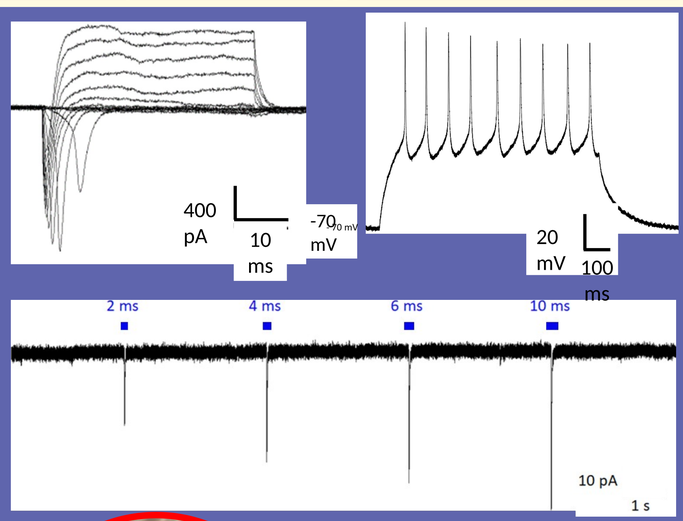
Abstract: Several retinal degenerative diseases like age-related macular degeneration (AMD) and retinitis pigmentosa (RP) cause total or partial blindness to about 1 over 4000 people in the world for a total of ~1.5 milion. Those diseases cannot be cured, the only possible improvement of life quality for the people affected is a visual prosthesis compensating the retinal damage. Such devices have been developed with interesting but limited results. We suggest an improved version based on subretinal implantation of SiPM arrays which should be able to stimulate the healthy part of the retina at low power and high visual acuity.



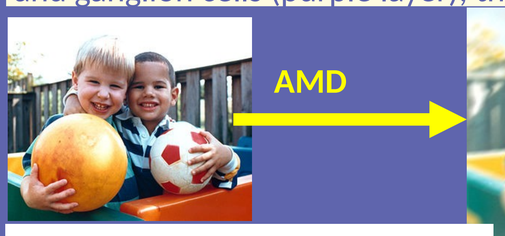
Rods, cones and nerve layers in the retina. The front (anterior) of the eye is on the left. Light (from the left) passes through several transparent nerve layers to reach rods and cones (far right). A chemical change in the rods and cones send a signal back to the nerves. The signal goes first to the bipolar and horizontal cells (yellow layer), then to the amacrine cells and ganglion cells (purple layer), then to the optic nerve fibres.



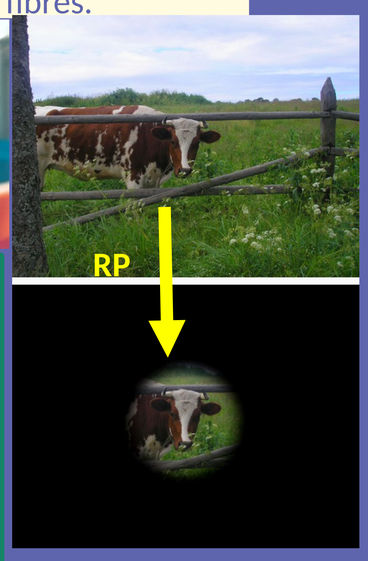




Cells survival on SiPM and functional characterization of differentiated SHSY-5Y cells.
A) Undifferentiated SHSY-5Y cells have been plated and cultured on a 35 mm Petri dish.
B) Following differentiation towards a neuronal phenotype.
C) Differentiated cells have been characterized by patch-clamp technique showing typical Na+ and K+ currents (left panel) and the ability to fire action potentials (right panel).
D) Following expression of Channelrhodopsin2 on plasma membrane, these cells could be activated by light (optogenetic stimulation) using LED light pulses at 470 nm with increasing duration 2-10 ms. The optostimulated cells generate a negative Na+ current which intensity is proportional to the duration of the stimulus.
E) Ability of SHSY-5Y cells to survive on a SiPM tested by culturing them directly on a chip surface. The undifferentiated cells survive for almost 7 days as visible in a 4x magnification.



AMD



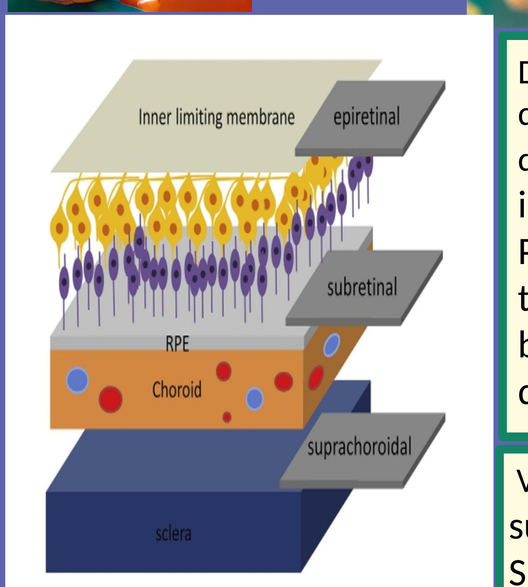


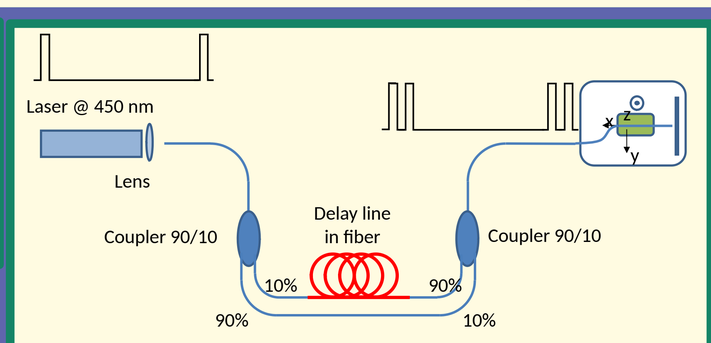
Fig. 3. Illustration of the implantation sites of the epiretinal, subretinal and supra-choroidal prostheses. Ganglion cells (yellow) and biploar cells (purple) are shown and damaged/eliminated photoreceptors are not shown.

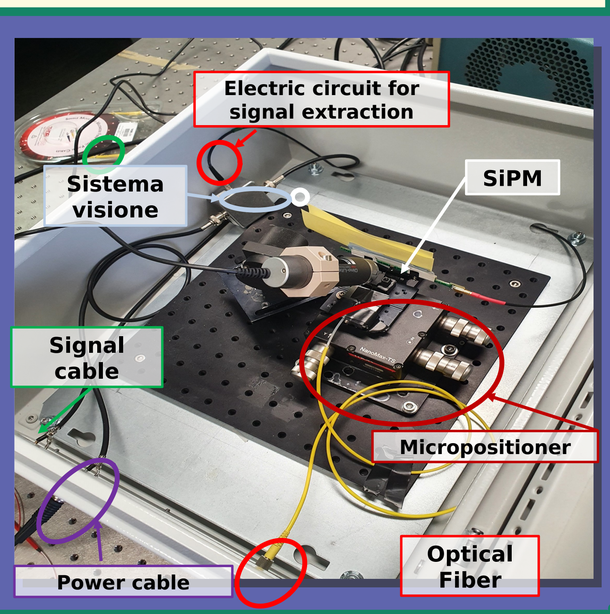
Due to retinal degeneration different visual impairment are Possible. With time total blindness can develop.

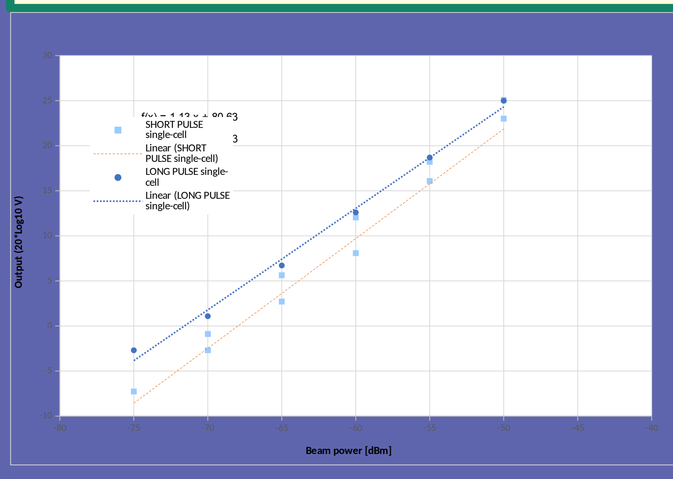
Visual prostheses can be epiretinal, subretinal or subcoroidal.
SPEye goal is to develop a subretinal prosthesis that allows to exploit the healthy retinal cells leading to the optical nerve.

Characterizing SiPM versus light power

We tested the dependence of the current output on the input light power using laser sources (red and blue) hitting a single SiPM cell.

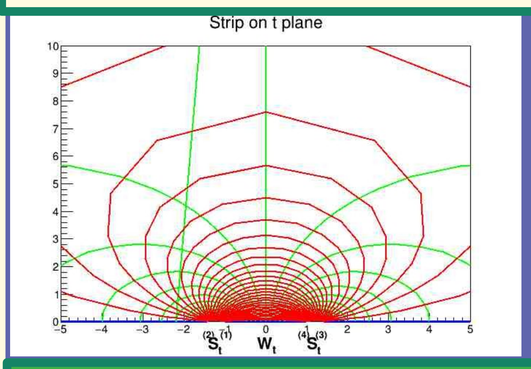




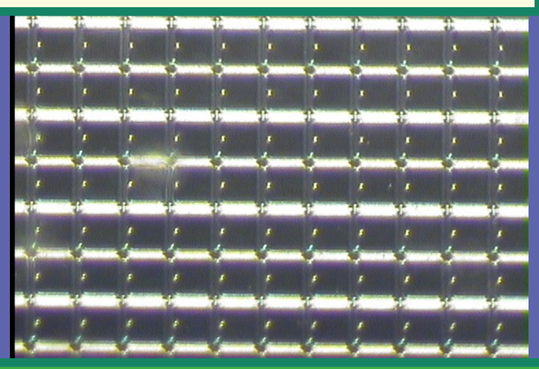


SiPM array as visual prosthesis

The diseases induced blindness is due to the rod and cone failure. They can be chirurgically replaced by other photodetectors inducing directly electrical signals to the innermost retina cells (horizontal, bipolar, amacrine, ganglion). SiPMs are interesting candidates because of their large internal amplification inducing large localized electric field even for low intensity light and of the small cell down to 10x10 μm^2.



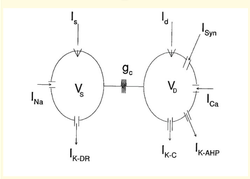
Shape of electric field between two adiacent SiPM array cells



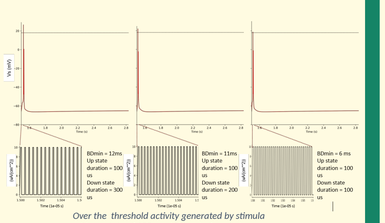
Microphotograph of SiPM array cells

Neuron simulation

Simulation of neuron response to SiPM signals



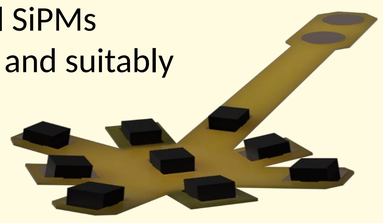
Pinsky-Rinzel model at two compartments. S and D label the



Over the threshold activity generated by stimula with up state of 100 us abd varyin frquencies.

Mechanical match

Large flat SiPMs poorly match the retinal spherical surface. Better match can be a set of small SiPMs connected together and suitably arranged.

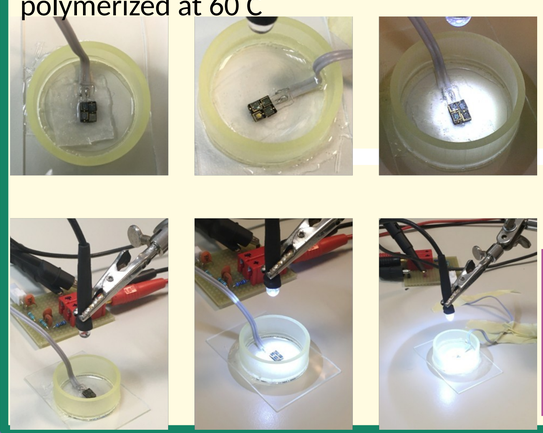


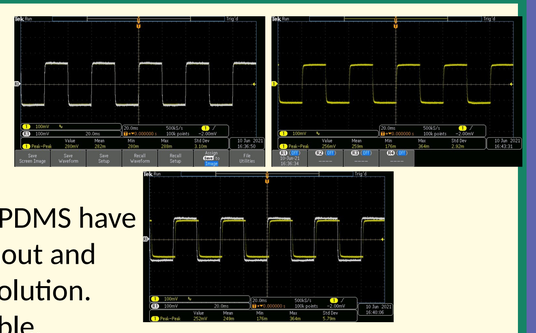
Items under study

- **SiPM Remote powering**
- **Living cell deposition on SiPM**
- **Characterization of response versus light power**
- **Simulation of neuron response to SiPM stimulation**
- **Mechanical matching of flat SiPM with spherical retina surface**
- **Biocompatibility and SiPM operation in physiological solution**

SiPM operation in physiological solution

4 SiPMs insulated with PDMS (Polydimethylsiloxane) polymerized at 60 C

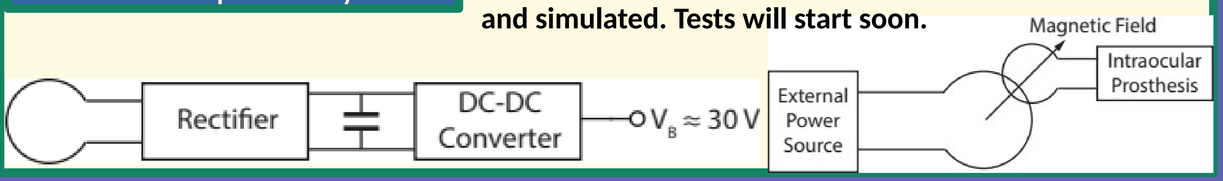




SiPM embedded in PDMS have been operated without and with physiological solution. No difference is visible.

The remote power system

The remote power circuit has been designed and simulated. Tests will start soon.



Web site

The project web site is https://speye.unipv.it/
Updated information are available there