

Retinal Implants: Charge transfer stability and sensitivity compared to visual results

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Abstract

Retinal Implants have the purpose to restore visual perception in blind patients suffering from retinitis pigmentosa (RP) and eventually also in very advanced forms of age-related macular degeneration (AMD). Electrical stimulation of the remaining retinal nerve fibre layers leads to visual sensations (phosphenes) [1, 2, 3]. Our retina implant, consisting of a light sensitive CMOS chip (1,500 pixels) and 16 separate direct stimulation (DS) electrodes, was recently tested successfully in a clinical pilot study [4]. Spectral sensitivity of the chip is quite different from the human eye. Therefore, while testing the system in vivo, ambient lighting conditions have to be carefully adjusted. In vitro measurements of chip spectral response for different wavelengths including infrared illumination are presented. We show that the charge transfer curve is not significantly altered during implantation. Hence we can use our initial measurement of charge transfer vs. illuminance to optimize illumination conditions for in vivo testing. With proper adjustment of brightness and chip response, small greyscale variations can be identified by the patient.

1 Introduction

Stimulation of retinal neurons via subretinal electrodes in humans has proven to elicit phosphenes reproducibly. Within a clinical pilot study, 11 patients with RP were provided with the implant for more than 4 weeks each [4]. Good spatial correlation between stimulation and perception was found, as well as visual perception of ambient light and locating abilities. These experiments were performed with a light sensitive CMOS chip [5] where all electrodes provided stimulation pulses simultaneously.

Compared to photopic trichromatic vision with our human eye, the sensitivity of the retina chip cannot differentiate wavelengths in the visible spectrum. In addition, photodiodes are sensitive to infrared (IR) irradiation. For clinical tests of the implant, the ambient light has to be carefully adjusted. The visual impression of colours may be misleading due to the fact that individual electrodes are stimulating different chromatic channels of the retina.

2 Stability of charge transfer in vivo

The CMOS chip consists of 1500 pixels with a photodiode and a differential amplifier in each pixel. The signal at the pixel output (electrode) is a biphasic current pulse with illumination dependent signal strength (Fig. 1). Integration of the current versus time results in a specific charge transfer to the retinal tissue. Maximum

charge transfer versus illuminance leads to a typical illumination dependent charge transfer characteristic curve as shown in Fig. 2. The slope of the curve is the ‘working range’ where contrast perception is optimum.

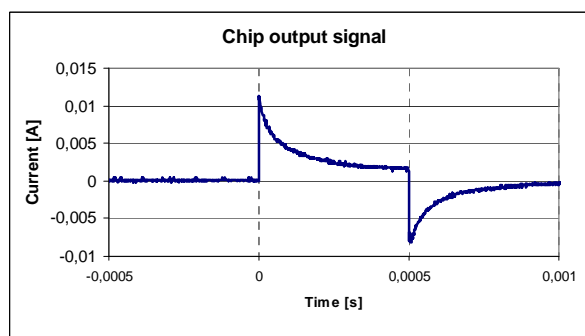


Fig. 1 Biphasic current pulse at the chip electrodes in vitro (Global output data taken from 1500 Pixels)

Adjustment of the charge transfer can be done by horizontally shifting the curve (via V_{gl}) and reduction of maximum charge (via V_{Bias}). Both voltages can be controlled from the outside.

Once the chip is implanted, the charge transfer is no more accessible for any measurement and it is known that electrode impedances may change in vivo. For this reason, it is important to know if the sensitivity curve changes qualitatively while the chip is implanted.

3 Spectral Sensitivity

Photodiodes are usually characterised by the responsivity which describes the generated photocurrent per light power. In case of the retina chip, the whole system consisting of photodiode, amplifier, electrode and electrolyte has to be considered. Evaluation of spectral response of a complete CMOS pixel was done by illumination with different wavelength laser diodes. Radiance at chip level was measured by use of a radiometer.

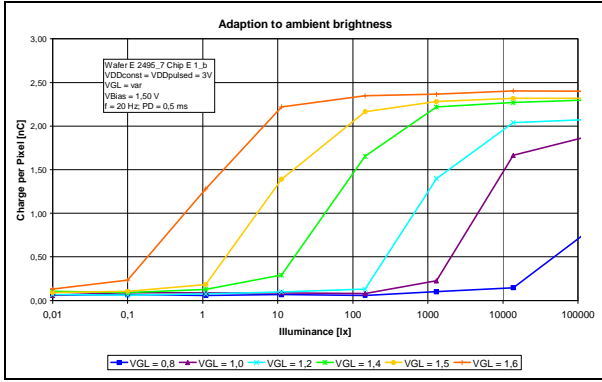


Fig. 2 Charge transfer adjustment for different brightness levels via Vgl (sensitivity curve)

Therefore, we compared charge transfer before implantation in patients with data after explantation which indicates the stability of charge transfer characteristics in vivo. The data taken before implantation (Fig. 3) and after explantation (Fig. 4) show qualitative consistency between both curves.

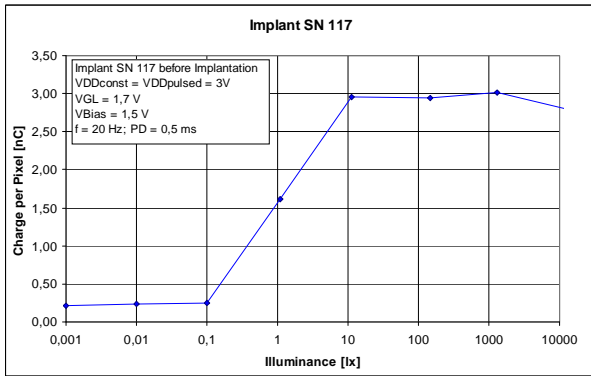


Fig. 3 Charge transfer before implantation

In this case, the period of implantation was 35 days. A possible reason for greater maximum charge transfer after explantation is a smaller lead resistance while testing the chip post explantation. The working range between 0,1 lx and 10 lx has not changed during the implantation period. Consequently, an initial characteristic charge transfer curve can be applied for individual adaptation of illumination conditions.

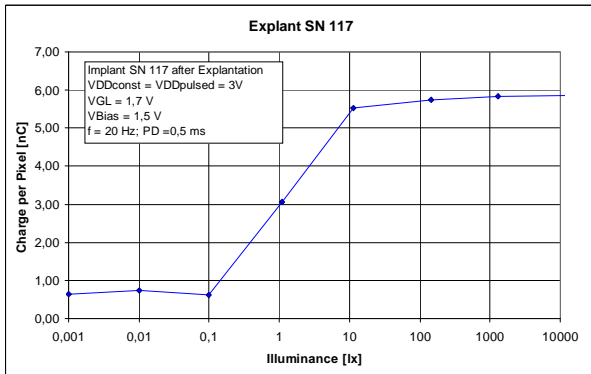


Fig. 4 Charge transfer after 35 days in vivo

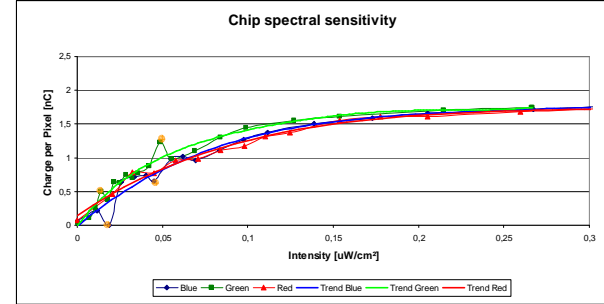


Fig. 5 Charge transfer is practically independent of wavelength in the visible range

Results of spectral response measurements are depicted in Fig. 5. There was no significant difference in charge transfer for 3 visible wavelengths (460 nm, 527 nm and 625 nm). Consequently retinal stimulation with this CMOS chip has a different transfer function compared to human photopic vision.

4 IR – Illumination

Unlike the human eye, photodiodes are sensitive to infrared irradiation. Charge transfer of the retina chip for illumination with 950 nm light was measured at different IR - radiances for different Vgl settings (Fig. 6)

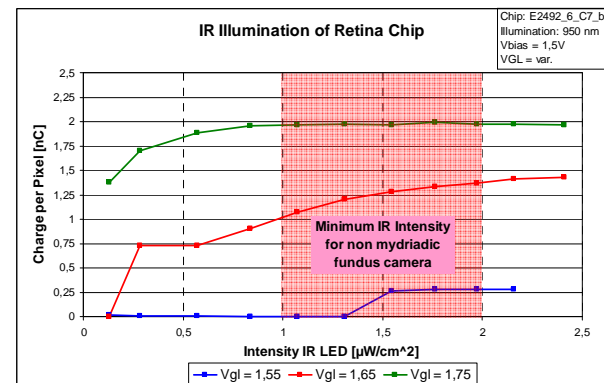


Fig. 6 Chip sensitivity to IR – irradiation

The minimum IR - radiance required for standard operation of a non mydiadic fundus camera is highlighted in Fig. 6. A considerable amount of charge is transferred to the retinal tissue even at low IR - intensities. Patients described the visual impression of this IR illumination as 'quite bright'. Hence, care has to be taken not to have strong IR sources close to the patient, as they would generate visual sensations. Spectacles with IR absorbing filters may be necessary for patients in order not to be irritated by strong heat sources.

5 Discrimination of different grey scales

During the course of our clinical pilot study, illumination of the research lab and the chip transfer characteristics were carefully adjusted. Brightness and colour of the room lighting could be adapted according to our requirements.

To confirm that these adjustments were successful, we presented square paper cards with a variety of different grey levels on a dark table cloth. The patient was asked to differentiate between two grey scales presented at any one time (Fig. 7).



Fig. 7 Patient discriminating different grey levels

The proband was able to identify the brighter grey level with a high probability. Correlation of the respective brightness with the charge transfer curve shows that within the working range, even small differences in brightness (2,6 dB) can be discerned (Fig. 8). A charge difference of 0.15 nC per pixel leads to visible contrast.

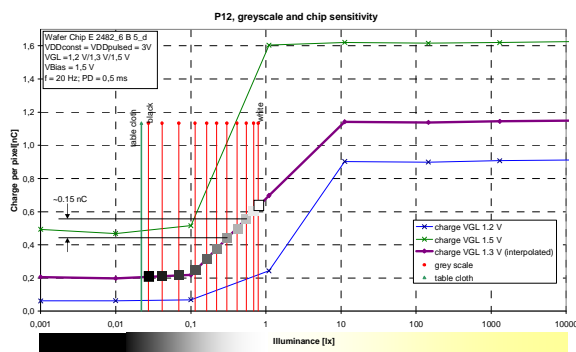


Fig. 8 Typical example of Retina Chip responses elicited by variations of grey levels. (Full paper in preparation by Wilke et. al.[6])

6 Reproduction of colour

The retina chip is almost equally sensitive to all colours and generates in the retina a greyish-yellowish like phosphene pattern. This is very different from the human eye, which is most sensitive to green light, and less

sensitive to red and blue light. As has been known in photography for many years, the colour sensitivity of black-and-white-films has to be matched to the colour sensitivity of the human eye (“panchromatic” films), otherwise b/w-copies of coloured scenes appear unnatural.

In order to simulate the effect of the non-panchromatic sensitivity of our chip, we have processed some colour pictures. Using the CIE spectral sensitivity values at the 3 visible LED wavelengths, the 3 colour levels in these pictures were adjusted in such a way, that they simulated a film material with equal sensitivity in the visible range, and then were converted to a b/w-picture (Fig.9: original picture, Fig.10: processed picture). It turned out, that pictures generally appeared more blurry than correctly processed (panchromatic) b/w-picture copies as borders between areas of different colour but equal irradiance are disappearing. However, in general, there should be no confusing information in the picture.



Fig. 9 Original Coloured Image



Fig. 10 Simulation (Processed Image)

7 Conclusions

The characteristic charge transfer of a retina CMOS chip does not change qualitatively in vivo. Therefore, the initial curve can be used to adjust the illumination during clinical testing. Spectral sensitivity of the chip is an important aspect while planning brightness and colour settings.

Coloured images or scenes generate a non-poly-chromatic ‘black and white image’ to the patient which adds some blurriness, but does not influence object visibility.

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8 Literature

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