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TOWARDS PHOTOVOLTAIC POWERED ARTIFICIAL RETINA

S.Silvestre[1], S. Bermejo[1], D. Guasch[2], P. Ortega[1] and L. Castañer[1]

(1) Micro & Nano Tech. Group. Electronic Engineering Department. UPC.

(2) Accessibility Chair. UPC.

Abstract: The aim of this article is to provide an overview of current and future concepts in the field of retinal prostheses, and is focused on the power supply based on solar energy conversion; we introduce the possibility of using PV minimodules as power supply for a new concept of retinal prostheses: Photovoltaic Powered Artificial Retina (PVAR). Main characteristics of these PV modules are presented showing its potential for this application.

Keywords: accessibility, artificial retina, PVAR.

Introduction

The number of cases of vision loss due to age, birth or accident, is increasing, in particular the dystrophies of the retinal photoreceptors, such as retinitis pigmentosa (RP) and macular degeneration (AMD), resulting in blindness for a significant number of people as described by Curcio, Medeiros and Millican (1996) and Humayun (2001).

The International Classification of Functioning, Disability and Health (ICF), established by the World Health Organization in 2002, is a universal classification of disability and health for use in health and health-related sectors. ICF implied a radical change because the stress shifted to health and functioning rather than on disability and illness. According to this new viewpoint, there were defined three domains, from body, individual and societal perspectives. This allows a holistic approach that includes both the level of capacity of the body and their level of performance in their usual environment in a social context.

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Disability therefore involves dysfunctioning at one or more of these same levels: impairments, activity limitations and participation restrictions. Impairments are the problems in body function or structure such as a significant deviation or loss. Activity limitations are difficulties an individual may have in executing activities. Participation restrictions are problems an individual may experience in involvement in life situations.

Accordingly, this research is focused on finding a technological solution in the body level, specifically for retinal impairments, in order to mitigate the limitations of the visual activity. Obviously this would have an impact in the social participation of people with retinal dystrophies because their restrictions will be removed. Patients could benefit from a major independence, mobility, safety and in general, best quality of life. This is our final aim. Laser treatments described by Bressler (2001) have been identified as effective in treating macular degeneration in some cases and the research by Del Cerro (1987) and Accland (2001) indicates that retinal transplantation and gene therapy respectively, potentially can reverse visual loss caused by retinal degeneration. However the hereditary dystrophies of the retinal photoreceptors are still untreatable, leading to blindness.

Tassiker et al in 1956 showed for the first time the use of a semiconductor sensor behind the retina of a blind patient that was able to transiently restore the patient’s ability to visually perceive light.

Autonomous, implantable biomedical devices are primal goal in many areas of health care, as the treatment of some illnesses, and could be done in a more economically viable manner. This line of research, therefore, is applicable and useful for other artificial implants.

The state of the art of implantable bio-medical devices relies heavily on customized design and fabrication to provide flexibility, energy transfer and protection against the electrophysiological environment of the body. These specially tailored products require long time and clearance of regulatory issues, thereby dramatically reducing the competiveness of commercial initiatives. As in any other application field, the device performance is compromised to meet the requirements of available technologies.

We describe in this work the main antecedents of retina implant experiences and we also estimate the potential of Photovoltaic Powered Artificial Retina (PVAR) devices. PVAR aims to produce autonomous, miniature, implantable bio devices, using photovoltaic conversion.

Photovoltaic Powered Artificial Retina (PVAR)

Several research groups have investigated on retinal prostheses, from electrical stimulation of retinal neurons to surgical implantation methods (Eckmiller, 1997; Chow & Chow, 1997; Rizzo & Wyatt, 1997; Humayun, 2001).

The most followed approach is to use electrical stimulation of parts of the visual system undamaged, by means of microelectrodes. Microelectrodes have been used in two configurations: subretinal and epiretinal.

The epiretinal approach (Eckmiller, 1997; Humayun, 2001; Rizzo & Wyatt, 1997), incorporates electrodes on the ganglion cell side of the retina and no light-sensitive elements are used. The epiretinal implant is a chip receiving electrical signals from a distant camera and processing unit (Dogulas Yanai et al. 2007; Veraart C. et al. 2003; Humayun et al. 2003. The implant generates electrical pulses conveyed from the optic nerve to the brain.

In the case of subretinal approach however (Chow & Chow, 1997; Zrenner et al., 1997), the electrodes are placed in between the retina and the retinal pigment epithelium. Light-sensitive microphotodiodes equipped with microelectrodes are placed in the subretinal space between the pigmented epithelium and outer layer of the retina. The light incoming on the retina generates currents in the photodiodes which activate the microelectrodes, resulting in stimulation of retinal sensory neurons.

In few examples, such as in Chow et al. (2001) the energy required is coming from the incident light, whereas in most of the cases an external source of energy is required. Among the several means to provide this extra energy, experiences with wiring and more recently (Mokwa 2011) with RF-coupling using an inductive link, directly placed in front of the eye can be found.

Complex microelectrodes are also required made of inert materials, in a sufficient number. Moreover the charge injection by the microelectrode to excite retinal neurons is critical (Margalit et al. 2002).

Visual perceptions depend on the main parameters of the stimulation signal such as the amplitude and duration among others.

In vivo experiments (Weiland et al. 1999) revealed that current threshold can be in the range of 100–600 μA and charge density of 0.8 to 4.8 mC/cm^2. An idea of the size of the implants experimented, is provided by the work of Chow et al. (2004) who were able to include up to 5000 microelectrodes in a 2 mm-diameter silicon based device.

PVAR can accomplish the main requirements of subretinal implants, as providing extra energy more electrodes could be implanted with enough power. PVAR has a great potential in this application as it has been show that smart miniature PV modules can be made flexible and can be encapsulated using bio-compatible materials. Furthermore this idea is compatible with embedded integrated circuits and sensors to provide computational sensing and communication capabilities. PVAR novelty is therefore twofold: no need for bulky inductive components, and modularity of the power supply.

Mini PV minimodules

Miniature photovoltaic (PV) modules have been developed at the group of Micro and Nano Technologies of the Electronic Engineering Department of the UPC, as power supply (Ortega et al. 2008).

The PV minimodules, having an area in the range of 0.5 cm^2, consist on an array of individual photovoltaic cells connected in series to fulfill the voltage required by the application. The photogenerated current is proportional to the individual solar cell area.

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The fabrication process steps starts with a commercial Silicon-On-Insulator (SOI) c-Si p-type <100> wafers. A SOI wafer consists on an active p-type layer, of small thickness (5 and 10 µm in our devices), on top of a handle wafer, 400 µm thick, which acts as mechanical support; in between the active layer and the handle wafer there is a buried oxide layer of approximately 1 µm. The top active layer is where individual solar cells are fabricated and they are isolated from each other by means of trenches anisotropically etched. Emitter and base contacts of the photocells are both in the front side of the wafer, making easy the series interconnection of cells performed by metallization and patterning (Figure 1).

Different PV minimodule Topologies of 9, 25, 49, 81 and 169 cells in series have been fabricated (Figure 2). Average electrical results of open circuit voltage, Voc, short circuit current, Isc, and maximum density power, Pm, are shown in Table 1. The results are an average from 3 up to 5 measured devices.

Figure 1. Cross section showing interconnection of solar cells forming the PV minimodule.

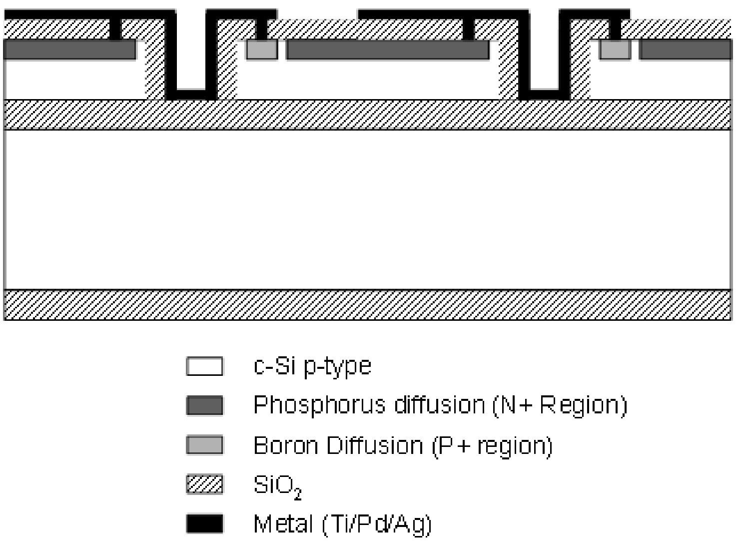

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Figure 2. Photovoltaic minimodules of 9 (a), 25 (b) 81 (c) and 169 (d) cells in series.

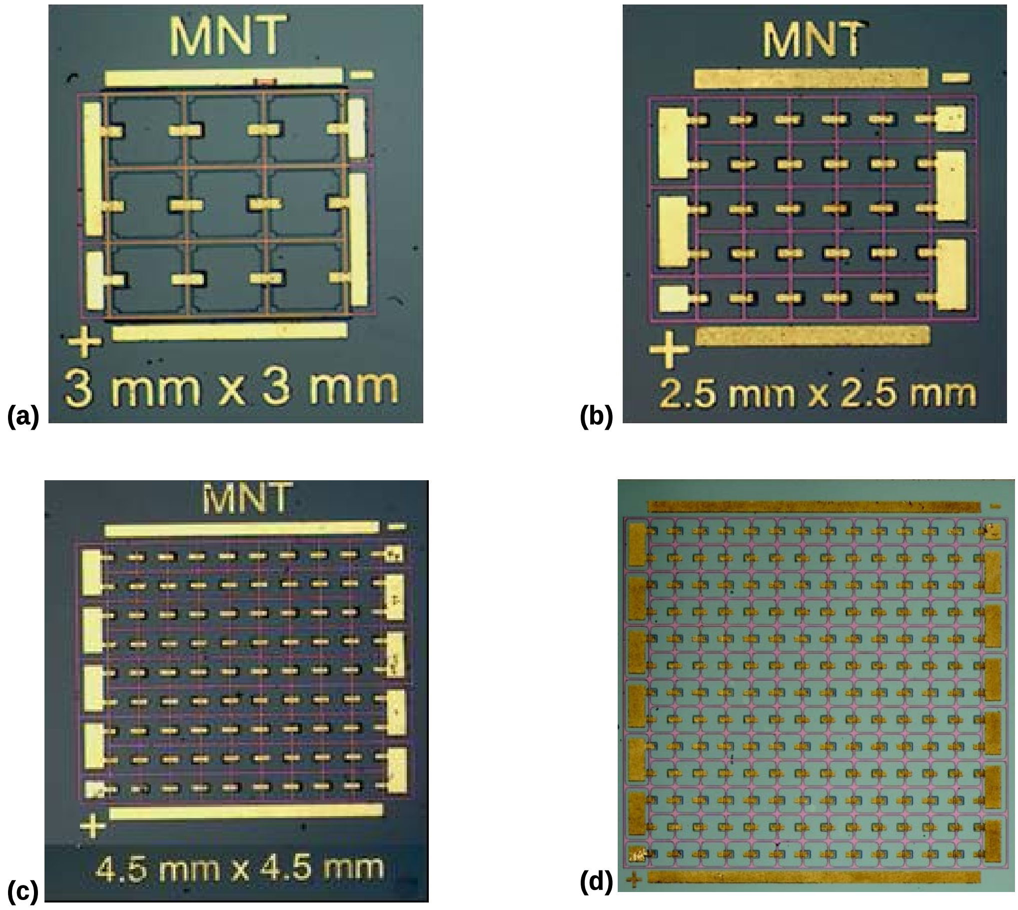


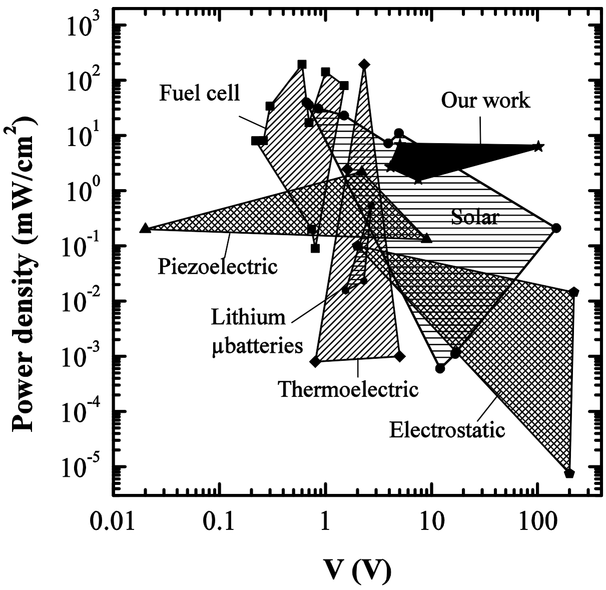
Table 1. Main electrical characteristics of the PV minimodules

Number of solar cells	V_{oc} (V)	I_{sc} (µA)	P_m (mW/cm^2)
9	5.6	200	4.1
25	15.7	179	4.9
49	30.3	194	6.7
81	47	42	6.7
169	71.6	43	3.0

The output power of the PV minimodules can be flexibly adapted to cover different ranges, adjusting conveniently output voltage and current, thanks to the interconnection technology of the solar cells forming the PV minimodule developed by the MNT. This allows the application of these PV minimodules as power supply to a wide range of low power applications having different requeriments, including high voltage applications, and especially to the PVAR.

The availability of power density offered by the PV minimodules outperforms most of competing power generation technologies nowadays on the market (Figure 3) and covers tipical power requeriments of main retina implant techniques described in the literature.

Figure 3. Comparison of power densities avalaible from different technologies used as power supply.



Conclusions

Mini photovoltaic modules, based in a new interconnection technology of high efficiency solar cells fabricated at the MNT of the UPC, have been introduced. The characteristics of these PV minimodules, in terms of area and power, have been discussed showing their potential as power supply for a new approach in the field of retinal prostheses, the Photovoltaic Powered Artificial Retina (PVAR).

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