Hybrid Microenergy Harvesters for Smart Contact Lenses

Yuanjie Xia
Microelectronics Lab
James Watt School of Engineering
University of Glasgow
Glasgow, UK.
2289015x@student.gla.ac.uk

Hadi Heidari
Microelectronics Lab
James Watt School of Engineering
University of Glasgow
Glasgow, UK.
Hadi.Heidari@glasgow.ac.uk

Hua Fan
School of Electronic Science and Engineering
University of Electronic Science and Technology of China
Chengdu, China.
fanhua7531@163.com

Rami Ghannam
Microelectronics Lab
James Watt School of Engineering
University of Glasgow
Glasgow, UK.
Rami.Ghannam@glasgow.ac.uk

***Abstract*—Smart electronic contact lenses typically integrate communications modules, electronic circuitry, sensors and an energy storage reservoir. These smart contact lenses can be used in medical applications that include monitoring patient glucose and intraocular pressure (IOP). However, due to the health hazards associated with chemical batteries, as well as the inconvenience of consistently charging the energy storage reservoir, a sustainable and reliable energy harvesting system is required. Therefore, the aim of this research is to design and develop an optimised harvester for a contact lens application. In fact, this paper introduces a novel hybrid microenergy harvester concept, which aims to produce sufficient electricity to power an electronic contact lens using light and electromagnetic radiation that are scavenged from photovoltaic cells and radio frequency technology.**

***Index Terms*—Contact Lens, Energy Harvesting, Wearable Electronics**

I. Introduction

Advancements in the microelectronics industry have enabled the integration of electronic components on soft contact lenses. Therefore, these smart or electronic contact lenses can be used as effective health monitoring platforms for measuring glucose [1] and intraocular pressure (IOP) [2]. However, to ensure uninterrupted and long term monitoring of patients, these platforms require self-sustainable and autonomous power. This can be achieved using energy harvested from the lens' external environment. Moreover, a hybrid microenergy harvester that combines the advantages of more than one harvester, while mitigating the limitations of each, is particularly beneficial for such an application.

Based on the power requirements of the smart contact lens, we have therefore selected two different kinds of microenergy harvesters. We also demonstrate the feasibility of combining these harvesters in a hybrid method to ensure continuous and self-sustainable power supply.

Various energy harvesting solutions have been proposed in the literature for smart contact lenses. For example, Yuan *et al.* demonstrated a wireless health monitoring contact lens powered by radio frequency (RF) [3]. In addition to RF energy, an abiotic glucose fuel cell was devised by Frei *et al.*. These researchers explored the feasibility of harvesting energy from metabolites in tear fluid [4]. Moreover, the concept of using flexible solar cells on contact lenses has been previously proposed by de Roose *et al.* [5]. Despite their intermittent nature, these cells are particularly attractive for wearable applications due to their high energy density. Consequently, we will explore the use of solar and RF energy sources for a smart or electronic contact lens. This combination of harvesters is particularly attractive, since the amount of harvestable energy is predictable [6].

According to the literature and depending on the application, the total power consumption of an electronic contact lens varies between 0.14μW and about 25μW [5], [7]–[9]. The power consumption of the lens' driver chip depends on its process, architecture and frequency. To design a self-sustainable contact lens system, the ideal power consumption should be no more than 10μW. Figure 1 shows our proposed design for a self-powered contact lens based on solar cells and RF energy harvesters.

In the subsequent section, we will describe our methodology in developing the harvester and assess the benefits as well as the drawbacks of these different power solutions.

II. Method

To design the hybrid harvester, we will develop a multiphysics simulations model of the system, which will be used to optimise the harvester design. The simulations model will be compared with experimental data. For the purpose of our simulations, we will rely on the use of either COMSOL or FlexPDE. These tools will be used for optimising the design

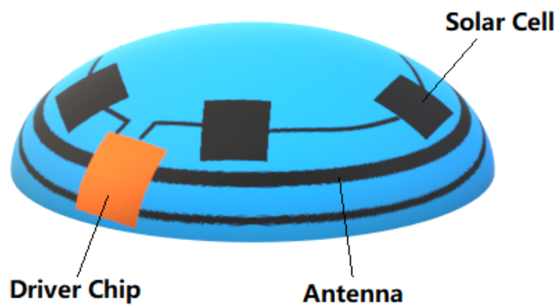

Fig. 1. Self-powered contact lens with hybrid energy harvesters

of RF harvesters in combination with solar cells. The power management unit will include a rectifier circuit, low pass filter and low dropout regulator (LDO). These components ensure the stability of the output voltage to the contact lens components.

A. Solar Energy

Solar cells are among the highest energy density harvesters available today. For outdoor applications, typical power conversion efficiencies (PCE) for AM1.5 conditions vary between 10.5% for thin film crystalline materials to 26.7% for silicon solar cells [10]. However, these PCE are for rigid materials, which are non ideal for wearable contact lens applications. Moreover, solar energy harvesting is intermittent and is severely reduced in indoor or implantable conditions. For example, Zhao *et al.* indicated that the amount of harvestable power in a $6mm^2$ implantable solar cell is approximately 84μW [11], [12]. Thus, an additional harvester is required to overcome these limitations.

B. RF Energy

Harvesting RF energy from surrounding electromagnetic radiation ensures that power is not intermittent. In that case, a loop or spiral antenna at the edge of the contact lens can be used. In the literature, when a contact lens with integrated antenna was placed 1.0 m away from a 1 W RF source, it could harvest around 100μW in free space. In a saline solutions, the received power dropped to nearly 10μW [13]. These experiments demonstrate that RF energy might not be sufficient to satisfy the power requirements of an electronic or smart contact lens. However, it can be used to overcome the intermittent nature of solar energy harvesters.

III. Conclusions

The design of a microenergy harvester for a wearable contact lens application first requires an understanding of the typical power requirements. Moreover, the size and design of electronic components and circuitry need to be arranged to overcome vision blocking. Additionally, the harvester needs to ensure continuous power supply. Despite the high energy density of solar cells, they are intermittent in nature, which means that little or no energy can be harvested during indoor conditions or at night. Consequently, additional energy sources are required to compensate for this power shortage. Accordingly, harvesting electromagnetic radiation using RF harvesters may be a feasible option. Consequently, we have demonstrated a novel concept for harvesting energy in a smart or electronic contact lens using a combination of solar cells and RF harvesters. Such a harvester needs to be compact and yield a high energy density. Our future work involves developing a multiphysics model to simulate and optimise the hybrid microenergy harvester.

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