S5-2 A biocompatible active artificial iris

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Abstract

A contact lens mimicking an artificial iris is presented as solution for people suffering from iris deficiencies. As this is a biomedical device, biocompatibility is a key specification for material choice and design. The presented research focusses on oxygen permeability of the lens, as the eye depends on oxygen from the environment for functioning.

1. Introduction

Over the years displays have gained a more important role in our lives. They are used in televisions, laptops, tablets, cell phones, smart watches etc. Also in the medical world high-end display applications were introduced, where they are especially important in the field of medical imaging. However, there are also other medical fields where there is a large potential for the use of displays. One of those fields is the one of vision correction by contact lenses. Although the first conceptual contact lens design by the British astronomer Sir John Herschel in 1823 was only trying to solve ophthalmologic disorders in a passive way, today, research strives towards the integration of active components in a contact lens to further optimize and expand vision correction possibilities.

This paper describes a solution for people suffering from ocular iris deficiencies. One can subdivide the different deficiencies in 3 main categories. First of all, in iris transillumination the iris has lost part of its pigment, which makes the iris transparent for incoming light. Secondly, a geometrical deficient iris has normal pigmentation but cannot properly block light as it has an abnormal shape. Finally, a functional deficient iris is complete in shape, but cannot adapt to changing light intensity. Although different in origin, all three types of deficiencies will render the patient hypersensitive to light, i.e. photosensitive, as incoming light cannot properly be blocked by the iris. Different solutions are available on the market for those patients, but none of them are optimal, as they are passive devices and are unable to adapt to light varying circumstances. For example, many types of iris implants have a fixed size of iris aperture and cannot adapt to changing light intensity. Furthermore, they are expensive and invasive as surgery is needed to place them in the eye. A less expensive and invasive solution is a painted contact lens, but this remains also a passive solution without adaptation possibilities. This paper introduces a smart contact lens based on display technology that can be used as an active, light adapting and medical aid for people suffering from iris deficiencies.

2. Active artificial iris

2.1 Design

A smart contact lens can be defined as a contact lens that uses active electronic components to address a complex problem. Depending on the problem being addressed, different electronic components are needed. Considering for example iris deficiencies, for which the key electronic component is a display that consists out of different ring-shaped, concentric pixels that can be switched between a transparent and opaque state. By consecutively switching the rings from transparent to opaque from the outer ring to the inner ring the constriction of an iris is mimicked, while the dilatation of an iris is mimicked by consecutively switching the rings from opaque to transparent from the inner ring to the outer ring. This function is illustrated on the left in **Fig 1.** The display is based on liquid crystal (LC) technology because of its low driving voltage and power consumption [1]. An artist impression of the additional electronic components to assist with powering and steering of the display are illustrated on the right in **Fig 1.** When designing a biomedical device and making a material choice it is very important to consider biocompatibility, meaning that the contact lens mimicking the iris should not invoke any negative biological response to the eye and vice versa. Design and material choices related to biocompatibility will be discussed.

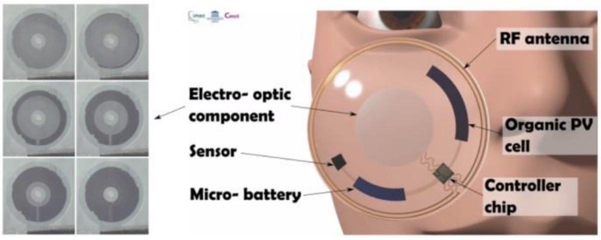

Fig 1. LC display with concentric rings (left); smart contact lens containing a LC display, powering and steering components (right).

2.2 Biocompatibility and material choice

As said, the display should be biocompatible because it is in contact with the human body. Since the display itself will be embedded in a contact lens made of materials that have already been deemed biocompatible and as such will not be in direct contact with the human body, the conditions seem less stringent. Also an encapsulation layer consisting of polymers and oxides deposited by atomic layer deposition (ALD) is being developed to ensure no transfer of species occurs between the eye and the interior of the contact lens, which includes the electronic components.

When considering biocompatibility not only the transfer of species should be controlled, but one should also not overlook the required oxygen permeability of the contact lens as the eyes use oxygen from the environment to function. Standard contact lens materials allow adequate oxygen transfer, but this is influenced by the integration of the display and other electronic components. This implicates that the oxygen permeability of the display should be as high as possible. However, this is in contrast with the fact that long term degradation of the liquid crystal in the display should be avoided by keeping the oxygen permeability minimal. As such a trade-off needs to be made between comfort and biological safety on the one hand and lifetime of the device on the other hand. With biocompatibility as a requirement, the substrates of the display device in **Fig 1** are made out of biocompatible PET foils. PET was chosen as it is flexible, transparent and can be easily thermoformed. It has decent strength and good chemical resistivity making it a suitable material for processing with microfabrication techniques. However, there are also two major disadvantages of using PET foils. First of all, PET is birefringent, which can interfere with the operation of the liquid crystal. Secondly, PET is not oxygen permeable.

2.3 Biocompatibility and design

As a non-oxygen permeable material is used as the display substrate, the display should cover as little real estate as possible. Since the human ocular iris never constricts completely, no LC must be present in the center of the display. The PET substrate can therefore be locally removed as illustrated in **Fig 2**. The central hole will allow extra oxygen to be transferred to the tear fluid and subsequently to the eye, exactly in the area where the need for oxygen is the greatest.

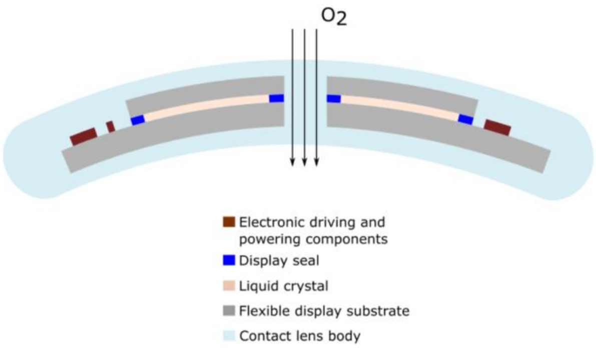

Fig 2. Cross section of the smart contact lens illustrating how a central hole in the display can allow extra oxygen transfer to the eye.

Another important design parameter is the thickness of the contact lens. Thicknesses of both standard rigid and soft contact lenses range between 100 µm and 160 µm [2]. When designing the display and taking into account that the display still needs to be embedded in a contact lens material, it is important to stay within this range to ensure maximal comfort. This implies that a display containing polarizers is not suitable for this application as the thickness of conventional polarizers is typically around 100 µm. Therefore, a polarizer-free LCD variant was chosen for the artificial iris, namely a Guest-Host LCD in White-Taylor variant.

3. Further research

3.1 More oxygen permeable display substrate

As PET is both birefringent and non-oxygen permeable, an alternative material might be more suitable as display substrate. One alternative is to use cellulose triacetate (TAC) foils as display substrates. TAC is biocompatible, non-birefringent and more oxygen permeable than PET. However, first experiments showed that TAC is less chemical resistant and more difficult to handle during processing. A second alternative is biocompatible thermoplastic polyurethane (TPU). TPU is also non-birefringent and more oxygen permeable than PET. Initial tests show promising results for TPU to be used as display substrates.

3.2 Design aspect to increase oxygen transfer to the eye

In addition to selecting an appropriate substrate material, special features can be added to the design to increase oxygen provision to the eye. One important design aspect concerns the integration and positioning of the electronic components around the display. When these components are integrated in the contact lens material, they will be placed on a carrier substrate that is connected to the contact lens. By providing holes in the carrier substrate in between the components, oxygen can be more easily transported through the oxygen permeable contact lens material. Furthermore, microfluidic channels can be provided in the lens to transport tear fluid with fresh oxygen to the eye. Also in the display other smaller holes can be created in addition to the big central hole.

4. Conclusion

A smart contact lens mimicking an artificial iris is presented for people suffering from iris deficiencies as an alternative for existing passive solutions. As this is a biomedical device, biocompatibility is an important factor during material selection and design. One crucial parameter in this biocompatibility is the oxygen permeability of the total device, as the eye relies on oxygen from the environment for its function. The initial selected display substrate, PET, is unfortunately not oxygen permeable so alternatives like TAC and TPU need to be tested. Furthermore, different ways of creating holes to allow oxygen transfer through the display and contact lens need to be investigated.

Acknowledgement

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References

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