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Leading opinion

Realizing the concept of a scalable artificial iris with self-regulating capability by reversible photoreaction of spiropyran dyes

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ABSTRACT

We report a scalable artificial iris with self-regulating spoke patterns of a liquid crystalline polymer that resemble the iris frills of the human eye. The underlying concept relies primarily on the reversible photo-induced conformation change of spiropyran dyes embedded in a transparent polymer. The spoke patterns around the scalable pupil, defined by selective wetting inscription, were produced using reactive liquid crystalline mesogens on a flexible substrate through polymerization. The self-regulation capability of our artificial iris, not requiring driving circuits and peripheral sensors, plays a central role in developing a new class of biomedical and photonic devices in a monolithic architecture.

1. Introduction

Particularly, biological systems have the ability to sense, regulate, grow, react, and regenerate in a highly responsive and self-adaptive manner. Among a number of the artificial organs including skins [1] and muscle tissues [2], the iris is one of the critical elements for those who suffer seriously from visual impairment. The iris of the human eye regulates the amount of the ambient light through the control of the aperture like a camera shutter. Iris defects associated with the physical damage or the congenital deformity such as (partial) aniridia [3] and albinism [4] result in severe glare, poor contrast sensitivity, and functional deterioration of sight. Requirements for an artificial iris are i) the biocompatibility with the human eye, ii) the capability of regulating light through it, iii) the simplicity in implementation like a contact lens, and iv) the structural conformation with the spoke patterns surrounding the pupil.

Till now, only a few cases of electrically controllable irises have been reported. For instance, an electro-optic effect based on a liquid crystal (LC) [5] or a polymer-dispersed LC [6] has been utilized for regulating the ambient light owing to the large optical anisotropy of the LC which enables to electrically control the light transmission at relatively low voltages. However, such approach requires inevitably a number of transparent electrodes and driving circuits in a bulky and complex structure, limiting the practical implementation into the human eye.

Here, we present a new concept of an artificial iris which provides the biocompatibility, the scalability together with the flexibility, the self-regulation capability without any peripheral component, and the spoke patterns resembling the iris frills of the human eye. It is found that the photo-induced conformation change of spiropyran dyes coated on a transparent polymer layer in the visible range leads directly to the self-regulation of light. The artificial frills, produced using a liquid crystalline polymer (LCP), represent the spoke patterns in the iris. Such unique features have not been demonstrated in an artificial iris so far.

The anatomical views together with the basic principles of a real human iris and an artificial iris in our work are illustrated in Fig. 1. The iris of the human eye is a contractile structure consisting of a front pigmented fibrovascular tissue, called the stroma, and pigmented epithelial cells beneath the stroma [7,8]. The sphincter muscle connected to the stroma contracts the pupil in circle while the dilator pupillae pulls the iris radially to enlarge the pupil. The apparent textures associated with the two muscles form the iris frills around the pupil as shown in Fig. 1A. The aperture of a real human iris changes to control the light intensity passing through the iris to the retina [9] as shown in Fig. 1B. As the ambient light intensity increases, the aperture decreases from r_d to r_b so that the light intensity reaching at the retina decreases. In other words, the iris regulates the amount of light by controlling the radius (Δr) of

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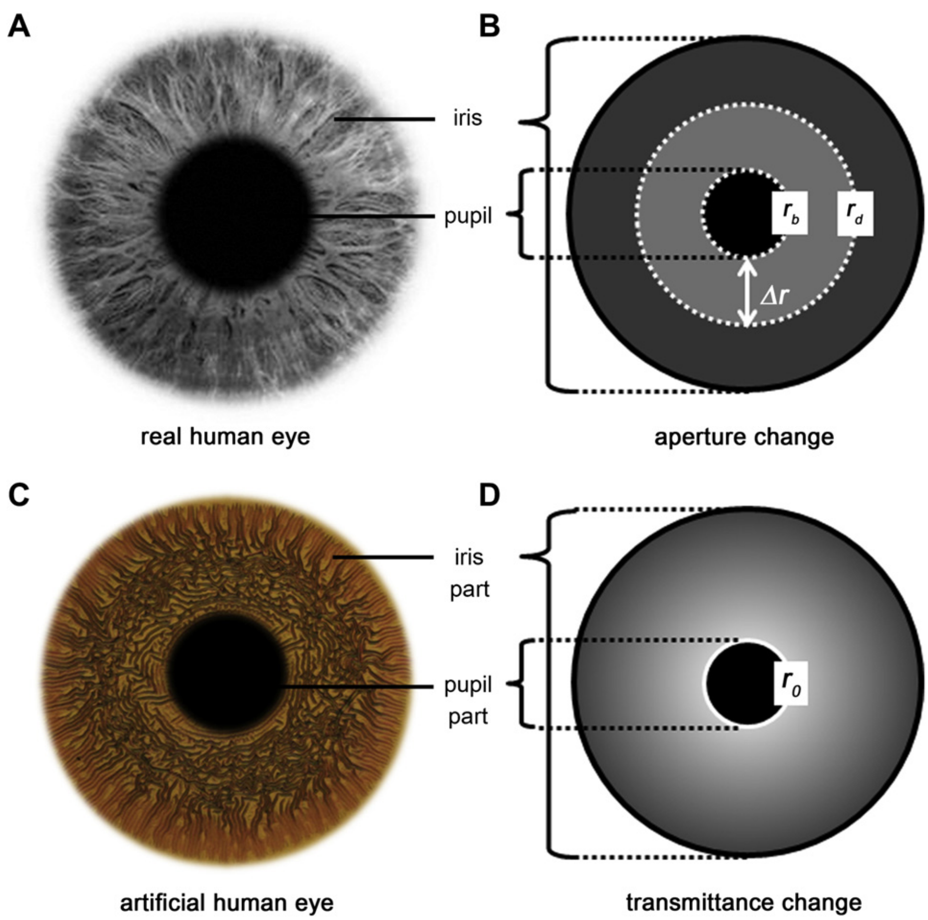

Fig. 1. Anatomical comparison of a human eye to our artificial eye. (A) An optical micrograph of a human eye. (B) The operation principle of a human eye. The human eye changes the aperture to regulate the amount of light incident to the retina. Here, the radius of pupil is r_d in the dark state and r_b in the bright state. The difference Δr varies with the light intensity reversibly. (C) The illustration of our artificial eye. The artificial eye consists of the pupil part and the iris part in analogy to the real human eye. (D) The iris part of the artificial eye is capable of self-regulating the transmittance by reversible photoreaction. The radius r_0 of the pupil part, corresponding to a typical pupil size of a human eye in bright, is fixed.

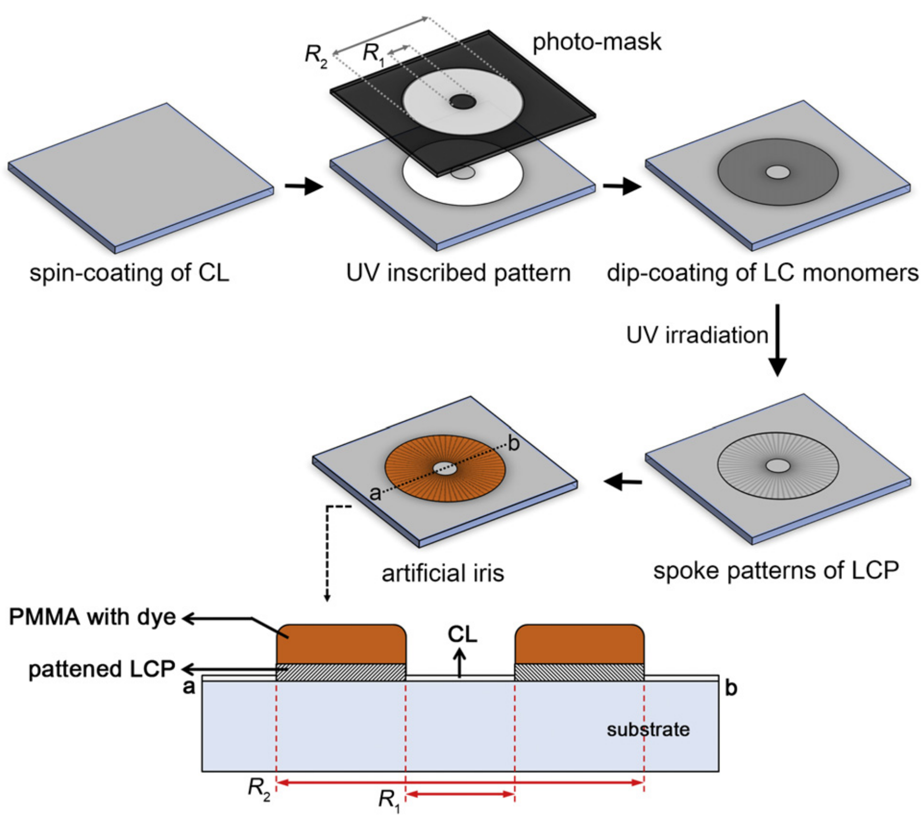

Fig. 2. Schematic diagram showing the fabrication processes of our artificial iris step-by-step using the SWI.