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Hybrid MEMS-SMA structure for intraocular lenses

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ABSTRACT

This paper presents the design, fabrication and evaluation of a novel ring-shape MEMS micro actuator for a latching mechanism for low power consumption and large displacement linear actuation, which can be applicable for a variable-focus lens system such as an accommodative intraocular lens (AIOL). The proposed actuator consists of a shape-memory-alloy (SMA) ring, parylene spring and shoes. The parylene spring was carefully designed for independent control of radial and axial stiffness, which can be realized by a high aspect ratio cross section and a meander structure. The maximum force generated by the parylene spring was about 50 mN. Two types of SMA actuator have been examined for the actuation: simple wire and micro spring types. The SMA in wire shape was evaluated in two configurations. Maximum displacement as high as 300 µm was obtained by using the SMA micro spring.

1. Introduction

Several ubiquitous portable devices would further benefit from small lens systems with an adjustable focus, as mobile phones, tablets and scanners. Besides, reliable adjustable focus is sought, for example, in artificial Accommodative Intraocular Lenses (AIOL), to restore the accommodation ability of the eye after replacement of the natural crystalline lens due to cataract surgery. The accommodation is a natural process performed by the ocular system that changes the total optical power of the eye, by means of the intraocular lens to get a sharp vision from objects located at long distances (infinity) and short distances (around 400 mm – typical reading distance). Such natural process is lost after replacement of the natural lens by an artificial lens. Recently, numerous innovations in the development of AIOL's have tried to restore accommodation [1], including a dual-optic setup we previously designed [2], on which the parameters for the micromachined structure herein presented are based .

A micro linear actuator is an important component of such variable-focus lens system, of which both large displacement and low power consumption (i.e. low heat generation) are required. Currently, a voice coil motor (VCM) or an ultrasonic motor (USM) are widely used as an actuator in lens systems. However, the VCM needs complex assembly process, and the USM requires high voltage. SMA, on the other hand, has the capability of large force with a quite simple structure [3], therefore it is a promising candidate material for the lens system. However, the demanded power is often higher than that of USM and VCM.

Another important material that can be used for this particular application is the Parylene C (poly(monochloro-*p*-xylylene)), a member of a unique family of thermoplastic crystalline polymers; its films are exceptionally conformal and chemically inert owing to its vapor deposition polymerization (VDP) coating process [4]. Parylene C has raised a particular interest in biomedical and lab-on-a-chip applications where stable and chemically inert surfaces are desired [5].

In this paper we propose a novel SMA linear actuator with latching mechanism for low power consumption actuation, which is composed of silicon, Parylene, SMA actuator and metal spring. This mechanism is the key to the proposed micromachined dual-optic lens system.

1.1. Lens system for intraocular application

The accommodation in an eye with its natural lens happens due to the change of the radius of curvature of the lens [6]. We designed and simulated a dual lens system to accomplish the role of the natural crystalline lens of the human eye with a relative displacement between lenses of up to 0.6 mm to accommodate images with objects located between infinity and around 400 mm [2].

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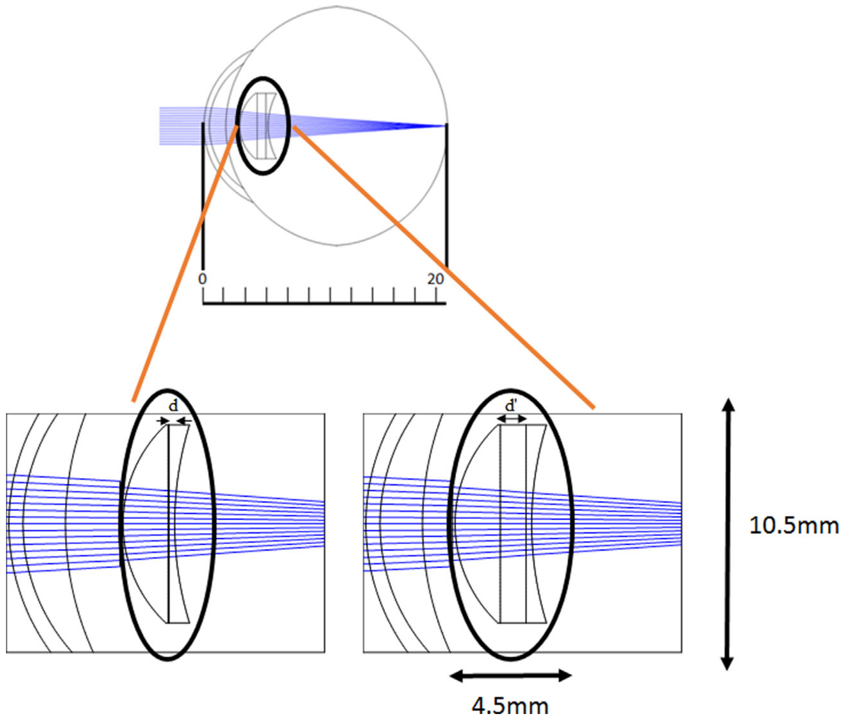

Fig. 1. Optical geometry and illustration about the capsular bag [2].

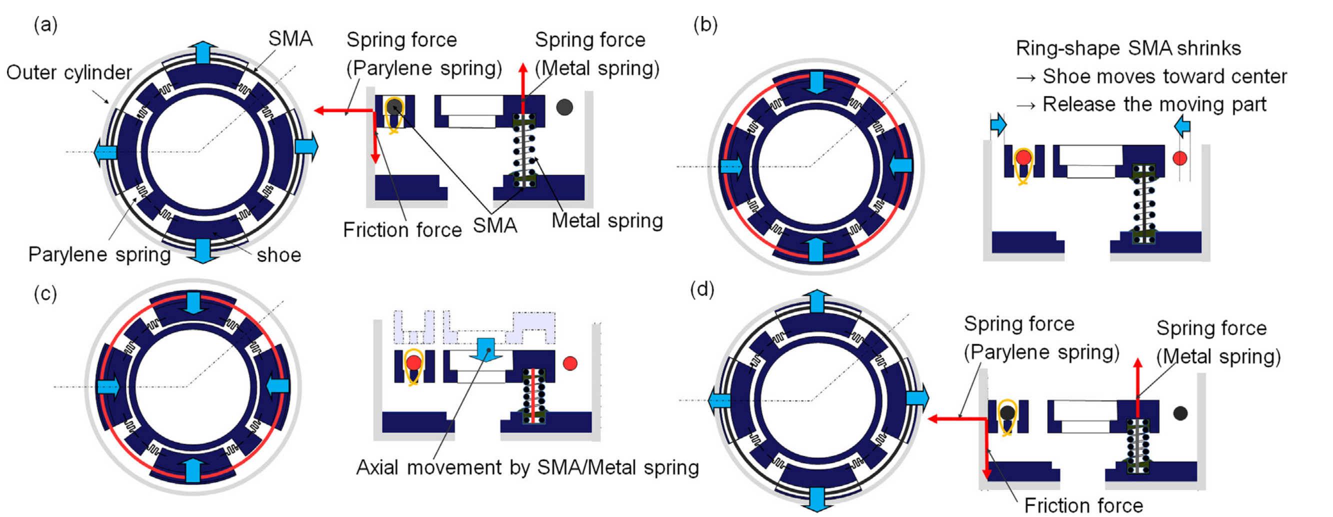

Fig. 2. Working principle of a latching mechanism. (a) Friction force and axial direction spring force are balanced in latched state. (b) Just before the axial direction movement, the ring-shape SMA is actuated to release shoes from the outer cylinder. Then (c) the axial position is adjusted by the axial SMA/metal spring. (d) When the ring-shape SMA turns off, the shoes are pushed against the outer cylinder, the axial position is again kept without any power consumption.

A drawing depicting the most important optical elements of the eye (cornea, anterior chamber, pupil, rear chamber, crystalline and retina [7]) and the capsular bag is shown in Fig. 1 [2], considering the proposed dual-optic intraocular lens. The diameter of the capsular bag is around 10.5 mm with a thickness of around 4.5 mm. The lengths *d* and *d*' represent the distance between the front and backside lens to accommodate far and near object to planes on the retina, respectively.

2. Low power-consumption SMA linear actuator

2.1. Structure of the device and principle of latched linear actuator

Fig. 2 shows the schematic of the proposed SMA micro linear actuator. A moving silicon part consists of a silicon ring, latching shoes, retention springs and a ring-shape SMA actuator. The retention spring made of parylene (Parylene C) is used to keep the initial position, when the ring-shape SMA is in a rest state. Parylene C (poly(monochloro-*p*-xylylene)) has some unique properties such as chemical stability, high electrical insulation, bio-compatibility, high flexibility and can be conformally deposited [4,8]. The moving part is supported by a co-axial SMA actuator and metal retention spring, which is used for axial movement.

The working principle of the latching mechanism is illustrated in Fig. 2. In a latched state (Fig. 2(a) and (d)), both ring-shape and axial SMA actuators are in the rest-state. The parylene retention spring presses the shoe toward the outer cylinder made of PMMA. The friction force between the shoes and the outer cylinder keeps the axial position of the moving part. The high aspect ratio parylene spring makes it stiff enough not to be deformed by the friction force.