Variable-focal lens using electroactive polymer actuator

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abstract

We present a simple and cost-effective design and fabrication process of a liquid-filled variable-focal lens using electroactive polymer as an actuator. The lens is made of soft polymer material, its shape and curvature can be controlled by pneumatic pressure. As an actuator, we used a carbon-polymer composite (CPC); likewise it is possible to use any other ionic EAP. The device is composed of elastic membrane upon a circular lens chamber, a reservoir of liquid, and a channel between them. It is made of three layers of polydimethylsiloxane (PDMS), bonded using the technics of partial curing. The channels and reservoir are filled with incompressible liquid after curing process. A CPC actuator is mechanically attached to reservoir to compress or decompress the liquid. Squeezing the liquid between the reservoir and the lens chamber will push the membrane inward or outward resulting in the change of the shape of the lens and alteration of its focal length. Depending on the pressure the lens can be plano-convex or plano-concave or even switch between the two configurations. With only a few minor modifications it is possible to fabricate bi-convex and bi-concave lenses. We report on a 1 mm diameter lens that can be converging or diverging with the focal length from infinity to 17 mm. The 5x15mm CPC actuator with the working voltage of only up to ±2.5V was capable to alter within the full range of the focal length in 10 seconds.

**Keywords:** Liquid lens, variable-focal, electroactive polymer, PDMS, CPC actuator

1. Introduction

Variable-focal lenses have been researched for years. There are several fields including beam steering and portable imaging where usage of tunable lenses could give an extra value. Variable-focal length lenses could be constructed without using mechanical translational movement thus noiseless design of the lens system is possible.

Tunable lenses could be classified as follows: electrowetting, gel type, and liquid lenses. Electrowetting lens is based on a drop of liquid which shape is changed by applied voltage. Alteration of optical power is obtained by electrowetting behavior of the droplet and the changes of its contact angle. Although these lenses have fast response time, authors have found it hard to reach larger apertures {{1040 Jong-Moon Choi 2008}}. Moreover, relatively high voltage (~50V) is required to operate {{1056 Hendriks,B.H.W. 2005}}{{1007 Shimizu,I. 2009}}.

Gel type lens is composed of elastic material that is contracted and expanded thus changing the radius of curvature. For instance SMA actuator has been used to control contraction/expansion {{1040 Jong-Moon Choi 2008}}. Gel type lenses are relatively resistant to vibrations and shocks but have limited focal range.

Finally, the concept of liquid lens uses three key elements: transparent elastic membrane (often made of polydimethylsiloxane – PDMS), liquid, and an actuator. The membrane is deformed as a result of pneumatic pressure in the liquid. As a result of deforming the membrane, the radius of curvature of the lens is changed and optical power is altered. For pressure control, different actuators like an external pump {{1024 Lin,Wei-Cheng 2008}} or directly connected piezostack actuator {{1021 Oku,H. 2009}} have been used. Compared to electrowetting lens, liquid lenses are able to produce wider range of focal length and the design of the lens is rather simple. Considering liquid lenses, there is also an option to choose between different actuators allowing the system to be more dynamic.

Electroactive polymers (EAPs) are materials that change their shape and size in response to applied voltage. These materials have large potential in the fields of microfluidics, robotics, and biomedicine. Although ionic EAPs, like ionic polymer metal composites (IPMCs), have been developed for years, they have been rather rarely used to drive tunable lenses. Shimizu *et al* {{1007 Shimizu,I. 2009}} have demonstrated a promising variable-focal liquid lens system which has four IPMC strips attached to deformable lens membrane. By moving the edges of a membrane towards the liquid, the deformation occurs in the opposite direction. Therefore, a variable-focal length is achieved.

Recently there has been an increasing interest in ionic EAPs based on carbon called carbon-polymer composites (CPC).

By using CPC actuator, the liquid lens system could be controlled using the voltage in the range of only 2.5 volts.

In current paper we propose a new approach to construct liquid-filled variable-focal lens by using partial curing technique of PDMS and CPC actuator. In this configuration large focal range is obtained by using low voltage.

2. STRUCTURE OF

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The article title appears centered at the top of the first page. The title font is 16 point, bold. The rules for capitalizing the title are the same as for sentences; only the first word, proper nouns, and acronyms should be capitalized. Avoid using acronyms in the title, unless they are widely understood. Consider the possibility that people outside your area of expertise might read your article. Appendix A contains more about acronyms.

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For books1,2 the listing includes the list of authors, book title (in italics), page or chapter numbers, publisher, city, and year of publication. A reference to a journal article3 includes the author list, title of the article (in quotes), journal name (in italics, properly abbreviated), volume number (in bold), inclusive page numbers, and year. By convention, article titles are capitalized as described in Sec. 2.1. A reference to a proceedings paper or a chapter in an edited book4 includes the author list, title of the article (in quotes), conference name (in italics), if appropriate, editors, volume or series title (in italics), volume number (in bold), if applicable, inclusive page numbers, publisher, city, and year. References to an article in the SPIE Proceedings may include the conference name, as shown in Ref. 5.

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2.7 Footnotes

Footnotes[[2]](#footnote-2) may used to provide auxiliary information that doesn’t need to appear in the text, e.g., to explain measurement units. They should be used sparingly, however.

3. SECTION formatting

Section headings are centered and formatted completely in upper case 11-point bold font. Sections should be numbered sequentially, starting with the first section after the Abstract. The heading starts with the section number, followed by a period. In MS Word the author must do this numbering.

Paragraphs that immediately follow a section heading are leading paragraphs and should not be indented, according to standard publishing style. The same goes for leading paragraphs of subsections and sub-subsections. Subsequent paragraphs are standard paragraphs, with 14-pt. (5-mm) indentation. There is a 5-pt. space between all paragraphs. In this MS Word template, this spacing is accomplished by including a 5-pt. space after each paragraph. Note that the indentation of a paragraph may be avoided in this MS Word by changing it to a leading paragraph.

3.1 Subsection Attributes

The subsection heading is left justified and set in 11-point, bold font. Capitalization rules are the same as those for book titles. The first and last words of a subsection heading are capitalized. The remaining words are also capitalized, except for minor words with fewer than four letters, such as articles (a, an, and the), short prepositions (of, at, by, for, in, etc.), and short conjunctions (and, or, as, but, etc.). Subsection numbers consist of the section number, followed by a period, and the subsection number within that section.

3.1.1 Sub-subsection attributes

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4. figures and tables

Figures are numbered in the order of their first citation. They should appear in numerical order and on the same page or after their first reference in the text. Alternatively, all figures may be placed at the end of the manuscript, that is, after

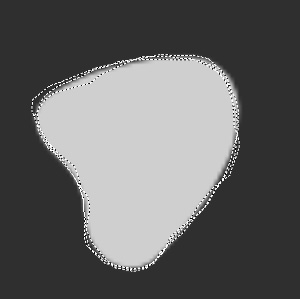


Figure 1. Figure captions are used to label the figure and help the reader understand the figure’s significance. The caption should be centered underneath the figure and set in 9-point font. It is preferable for figures and tables to be placed at the top or bottom of the page.

the Reference section. It is preferable to have figures appear at the top or bottom of the page. Avoid wrapping text around figures. Figures, along with their captions, should be separated from the main text by at least 0.2 in. or 5 mm.

Figure captions are centered below the figure or graph. Figure captions start with the figure number in 9-point normal font, followed by a period; the text is in 9-point normal font; for example, “Figure 3. Original image…” See Fig. 1 for an example of a figure caption. When the caption is too long to fit on one line, it should be justified to the right and left margins of the body of the text.

The author needs to supply the figure numbers in the order of reference in the body of the paper. It is often necessary in MS Word to move figures or tables around to achieve a satisfying appearance.

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appendix a. miscellaneous formatting details

It is often useful to refer back (or forward) to other sections in the article. Such references are made by section number. When the section reference starts a sentence, Section is spelled out; otherwise use its abbreviation, for example, “In Sec. 2 we showed…” or “Section 2.1 contained a description…”. References to figures, tables, theorems, etc. are handled the same way.

At the first occurrence of an acronym (unless it is widely known such as MTF, CCD, FFT), spell it out, followed by the acronym in parentheses, e.g., noise power spectrum (NPS).

A.1 Formatting Equations

Equations may appear inline with the text, if they are simple, short, and not of major importance; e.g.,  = *b*/*r*. Important equations appear on their own line. Such equations are centered. For example, “The expression for minus-log-posterior is

** = |**y - A x**|2 +  log *p*(**x**) , (1)

where  determines the strength of …” Principal equations are numbered, with the equation number placed within parentheses and right justified.

Equations are considered to be part of a sentence and should be punctuated accordingly. In the above example, a comma appears after the equation because the next line is a subordinate clause. If the equation ends the sentence, a period should follow the equation. The line following an equation should not be indented unless it is meant to start a new paragraph. In this MS Word template, indentation of a standard paragraph is avoided by changing it to a leading paragraph.

References to equations include the equation number in parentheses, for example, “Equation (1) shows...” or “Combining Eqs. (2) and (3), we obtain…”

A.2 Formatting Theorems

To include theorems in a formal way, the theorem identification should appear in a 10-point, bold font, left justified and followed by a period. The text of the theorem continues on the same line in normal, 10-point font. For example,

Theorem 1. For any unbiased estimator…

Formal statements of lemmas and algorithms receive a similar treatment.

ACKnowledgments

This unnumbered section is used to identify those people who have aided the authors in understanding or accomplishing the work presented and to acknowledge sources of funding.

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