Adaptive silicone-membrane lenses: planar vs. shaped membrane

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ABSTRACT

We compare the performance and optical quality of two types of adaptive fluidic silicone-membrane lenses. The membranes feature either a homogeneous thickness, or it is shaped resulting in an inhomogeneous cross-section. The lens systems incorporate a piezo actuator which is operated in a regime of ±40 V. The shaped membrane lenses show lower wave front errors than the planar ones, down to 24 nm. However, the system with a planar membrane achieves a larger refractive power ranging from +19 to -14 dpt. It also shows a shorter full scale response time (t_{planar} = 23.9 ms) compared to the shaped membrane (t_{shaped} = 35.4 ms).

Keywords: adaptive lens, wave front error, shaped membrane

1 INTRODUCTION

Adaptive lenses based on the electrowetting effect are commercially available. A lens of Varioptics (d_{ap} = 2.3 mm) shows a refractive power range of +10 to -8 dpt at a dynamic driving voltage of ±49 V. The wave front error WFE_{rms} of the adaptive lens is 24 to 76 nm [1]. Alternatively, we recently presented an adaptive planar silicone-membrane lens (d_{lens} = 5 mm) with a larger aperture and refractive power range [2, 3]. This paper concentrates on the optical characterization and the system performance of our adaptive lenses. Thereby, we analyze the influence of a lens membrane with homogeneous as well as with inhomogeneous thickness by simulation and measurement.

2 ASSEMBLY AND FABRICATION

The system consists of two components: lens and pump actuator, which are connected to each other on a glass substrate (fig. 1). The lens chamber is filled with immersion oil, and consists of a homogeneous or an inhomogeneous silicone-membrane and a supporting ring. The pump chamber, in which the lens liquid is also located, is made up of a piezo-bending actuator embedded in silicone. The exchange of liquid between the pump and lens chambers is enabled by orifices in the glass substrate. If a voltage is applied to the piezo-bending actuator, its interior bulges upwards so that the lens fluid is forced out of the pump into the lens chamber. This causes an increasing bulge in the lens membrane and thus as a result a reduction in the focal length of the lens.

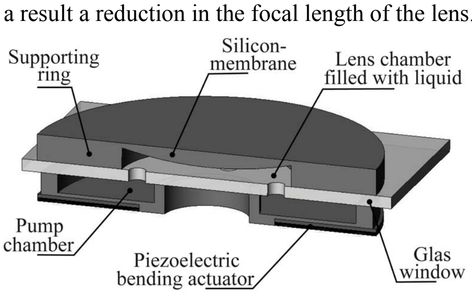

Fig. 1: Adaptive liquid lens with piezoelectric actuator.

Lens and actuator chamber are cast in a hot embossing machine in optical surface quality.

3 OPTICAL QUALITY

The theoretical lens quality is analyzed through the wave front errors with a mechanical FE-simulation and ray tracing.

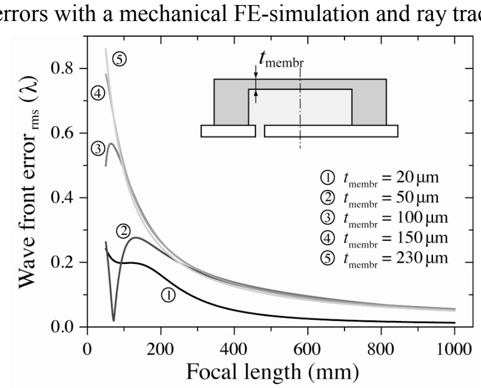

Fig. 2: Simulated aberration of the planar membrane lens as a function of the focal length. d_{lens} = 5 mm, d_{ap} = 2.5 mm

Lenses with homogeneous membranes (fig. 2) show low wave front errors above a focal range of 200 mm. They increase with increasing membrane thickness and decreasing

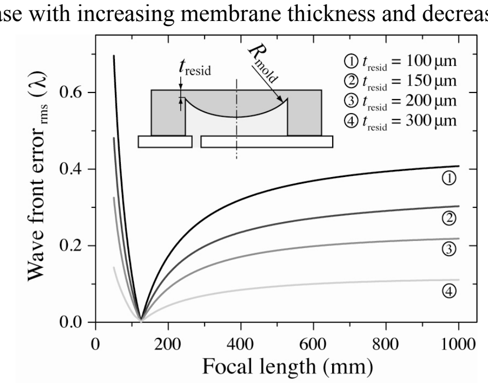

Fig. 3: Simulated aberration of the shaped membrane as a function of the focal length. d_{lens} = 5 mm, d_{ap} = 2.5 mm, R_{mold} = 10 mm

focal length. The lenses with inhomogeneous membranes (fig. 3) indicate the lowest aberration in the initial state. When the membrane is deformed the wave front error drastically increases for decreasing residual membrane thickness t_{resid}.

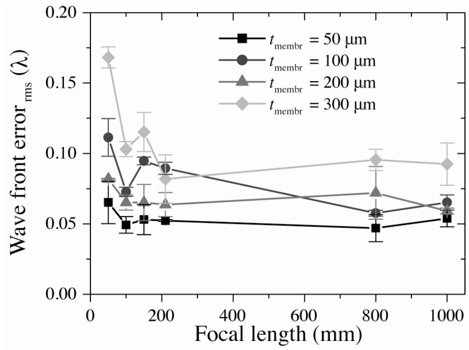

Fig. 4: Measured aberration of the planar membrane lens as function of the focal length. d_{lens} = 5 mm, $d_{aperture}$ = 2.5 mm

The optical lens quality is measured with a Mach-Zehnder-Interferometer [4]. Fig. 4 and fig. 5 show a good correlation to the simulations. For the inhomogeneous membrane we measured a very good minimum wave front error WFE_{rms} of 24 nm. Lenses with a homogeneous membrane show a higher aberration of 31 nm but a reduced increase.

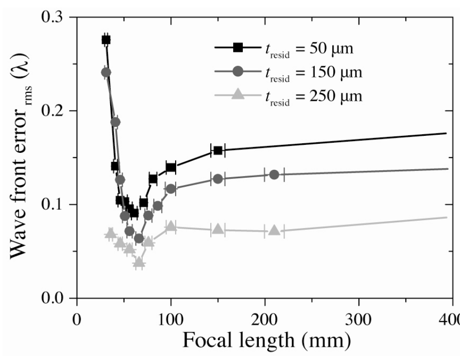

Fig. 5: Measured aberration of the shaped membrane as a function of the focal length. d_{lens} = 6 mm, $d_{aperture}$ = 2.5 mm, R_{mold} = 9.3 mm

4 SYSTEM PERFORMANCE

The system performance is analyzed with a laser profilometer. Fig. 6 displays the measured refractive power as a function of the piezo voltage. The system with the planar membrane show a refractive power range of +19 to -14 dpt, and the shape one a range of +9…+1 dpt. The reduced refractive power range of the system with an inhomogeneous lens membrane arises from the increasing membrane stiffness, respectively the increasing back pressure to the pump actuator. The hysteresis curve shape is typically for piezoelectric actuators.

For the dynamical characterization we measure the frequency response (fig. 7) and the full scale response time. The system with a shaped lens membrane shows compared to a planar membrane a more direct response characteristic, due to the lower membrane amplitude.

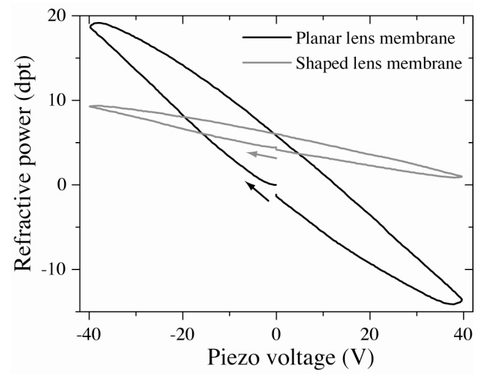

Fig. 6: Refractive power as a function of the piezo voltage for a system with a planar (t_{membr} = 60 µm) and a shaped (t_{resid} = 75 µm, R_{mold} = 9.3 mm) lens membrane.

The full scale response time is measured at a voltage step from +40 to -40 V and reverse. The system with a planar membrane indicates an isotropic response time of 23.9 ms and the lens with a shaped membrane a time of 35.4 ms. This arises from the higher lens back pressure of the inhomogeneous membrane, which let the response time increase.

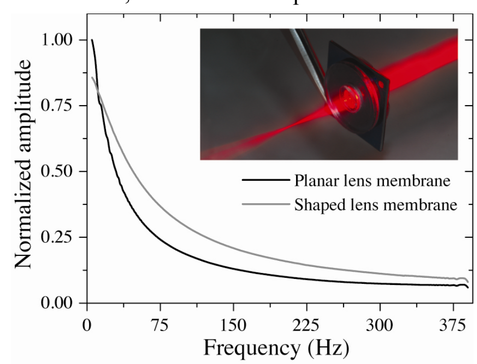

Fig. 7: Frequency response for a system with a planar (t_{membr} = 60 µm) and a shaped (t_{resid} = 75 µm, R_{mold} = 9.3 mm) lens membrane.

5 CONCLUSIONS

The use of adaptive lens systems with homogeneous respectively, inhomogeneous membranes is application specific. On the one hand, systems with planar membranes are reasonable for a large focal length range, a constant optical lens quality and a short response time. On the other hand, the application of lenses with shaped membranes are reasonable for a higher optical lens quality at a smaller focal length range around a working point.

6 REFERENCES

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