



Development of an Intraocular Pressure Measurement System

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Motivation



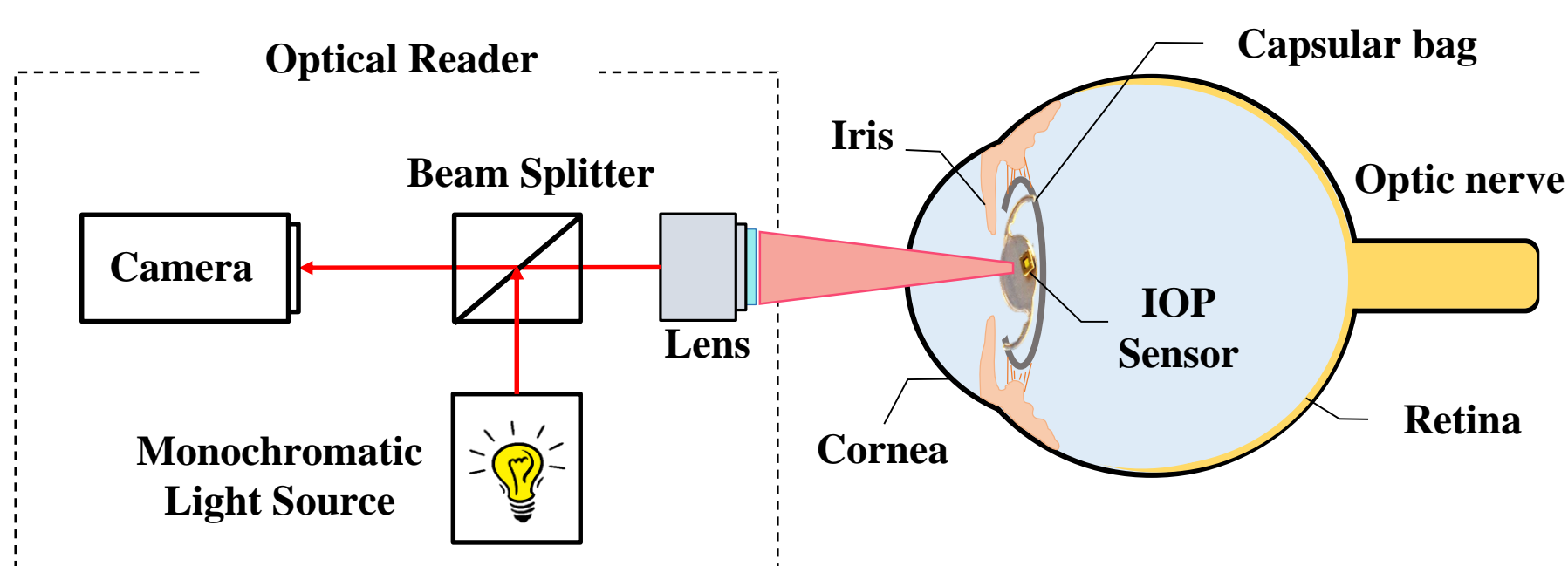
Normal Vision

Intermediate Symptom

Advanced Symptom

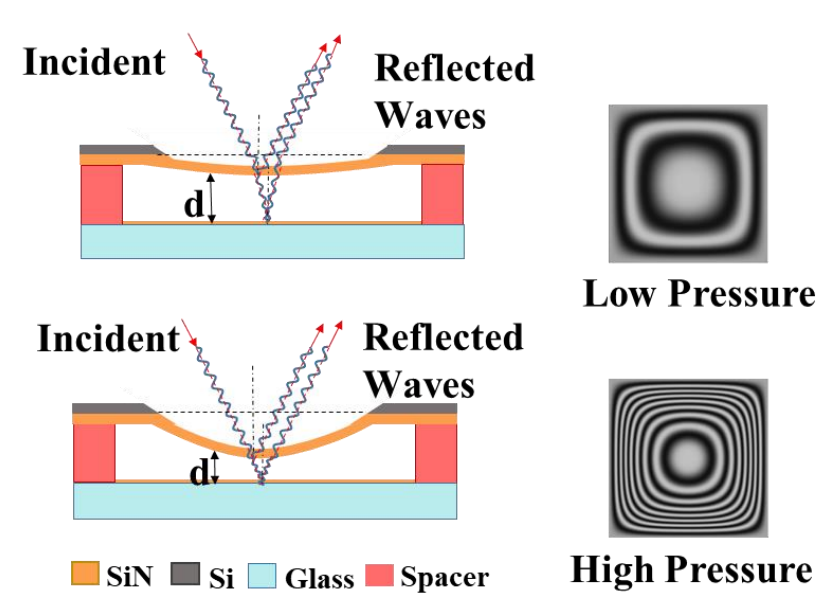
To date, elevated intraocular pressure (IOP) continues to be the primary risk factor for glaucoma due to its association with optic nerve damage and irreversible blindness. Current standard care, which involves routine IOP measurements during office visits, can only provide snapshots of the patient's IOP profile. In order to improve glaucoma care and determine the effectiveness of therapeutic treatments, there is a pressing need for frequent and reliable IOP data to better understand the relationship between elevated eye pressure and optic nerve damage. The objective of this project is to develop an optical pressure sensor that allows monitoring of the IOP on a frequent or semi-continuous basis.

Intraocular Pressure Measurement System



The measurement system consists of a hand-held reader designed to capture interferometric patterns from the implanted optical sensor. As shown in the figure above, the sensor is integrated onto an intraocular lens and implanted during standard cataract surgery. By directing the monochromatic light emitted from the reader towards the sensor, one can obtain the interference pattern and, consequently, the intraocular pressure.

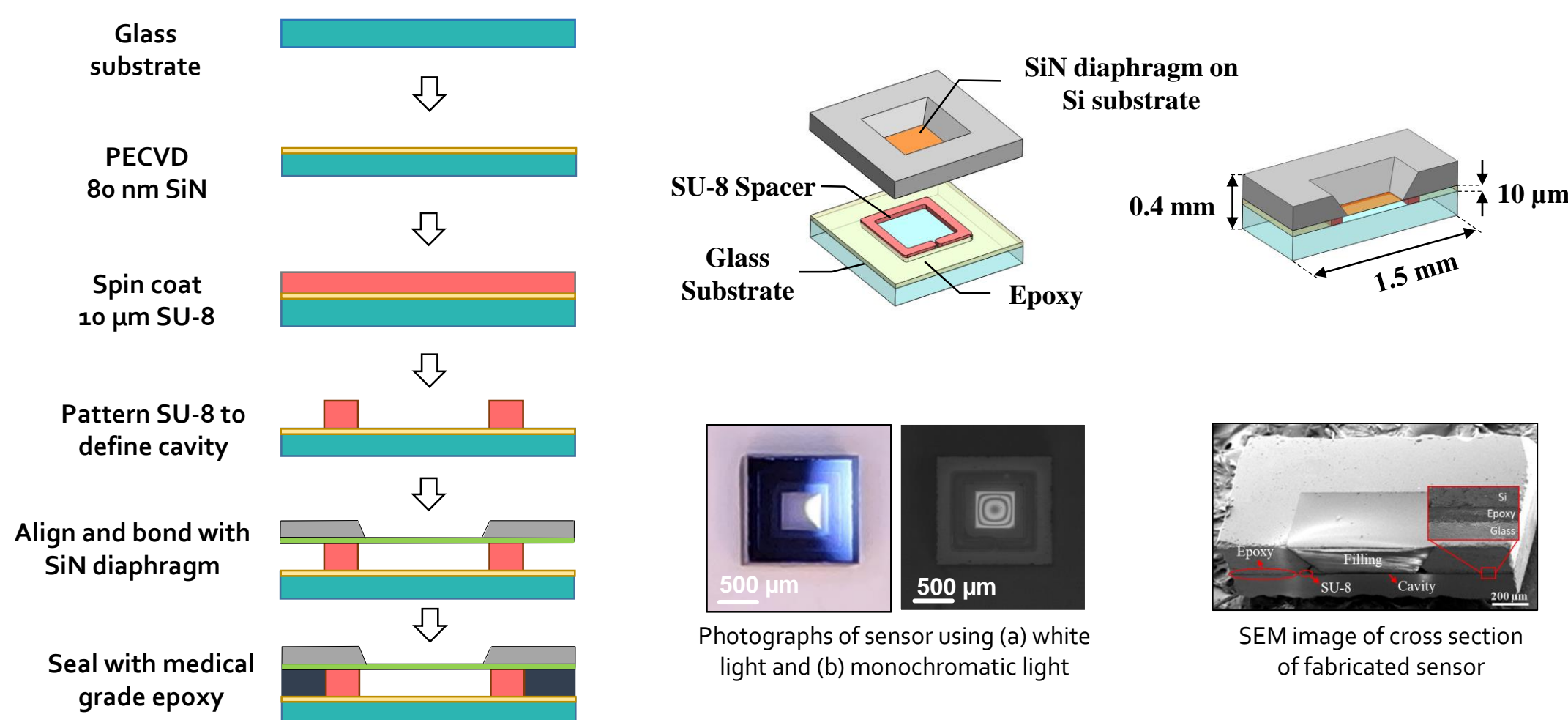
Optical Sensing Concept



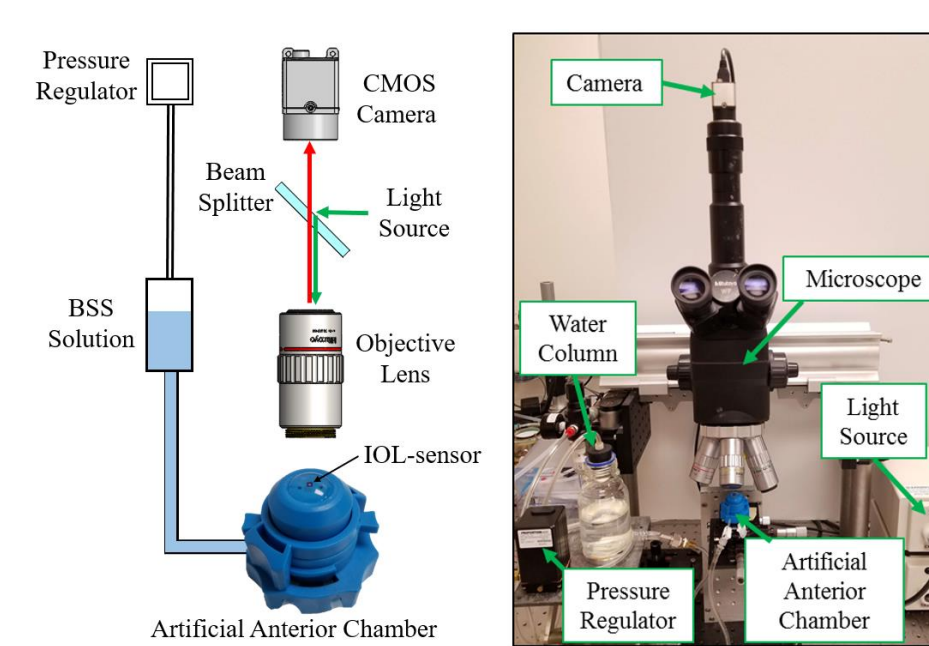
The sensor is designed based on the principle of interferometry. When monochromatic light is directed towards the sensor, reflected light waves from the bottom surface of the SiN diaphragm interfere with the reflected waves from the top surface of the SiN-coated glass substrate creating bright and dark fringes. The optical read-out of the sensor is captured using a camera and post-processed using image processing algorithm to correlate fringes pattern with pressure.

Sensor Fabrication

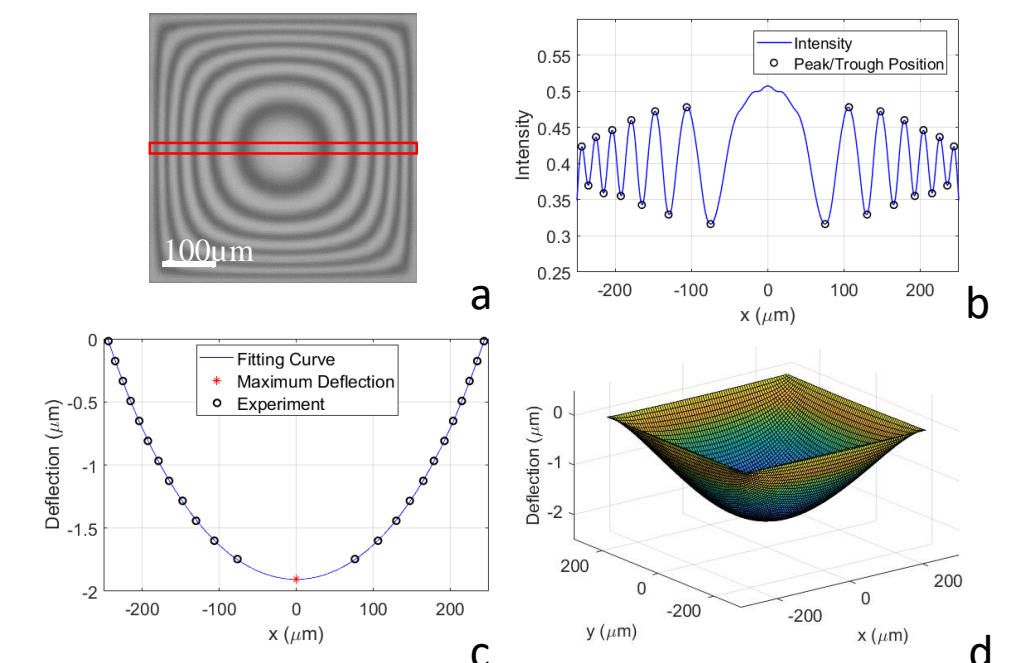
The sensor is fabricated by bonding a glass substrate with an SU-8 spacer to a silicon nitride diaphragm as shown in the process flow illustration. Once bonded using medical-grade epoxy to form a hermetic and watertight seal, the sensor was miniaturized to 1.5 mm x 1.5 mm using saw dicing to remove the excess sensor footprint.



Experimental Setup and Image Processing



A balance salt solution (BSS) column was connected to a pressure regulator and used to precisely control the hydrostatic pressure (± 0.1 mmHg) inside the artificial anterior chamber.

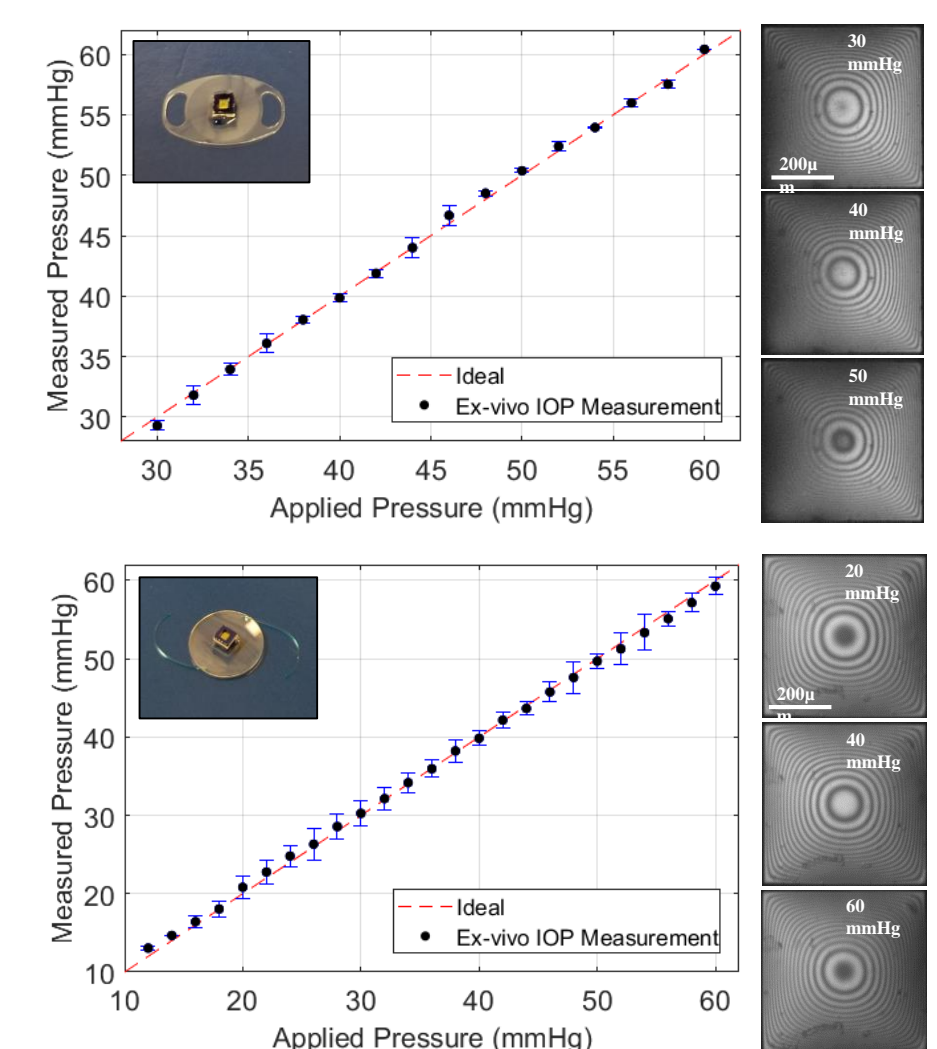
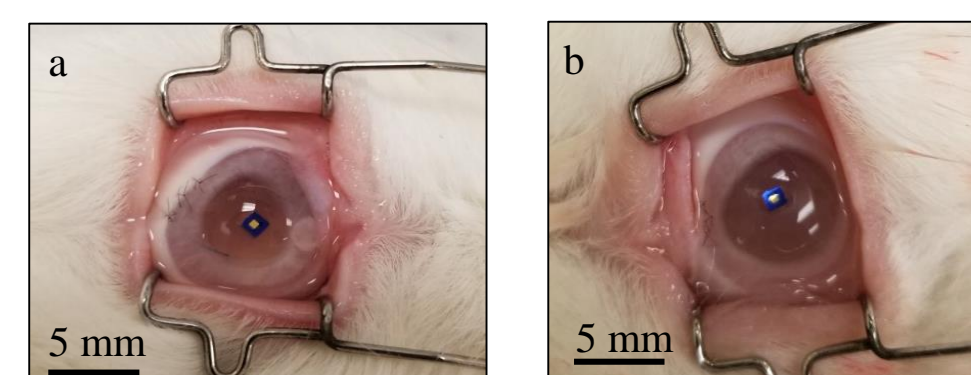


(a) Symmetric filtered fringe pattern (b) positions of bright and dark fringes (c) 2-D deflection profile across the diaphragm (d) 3-D surface reconstruction of the diaphragm deflection profile.

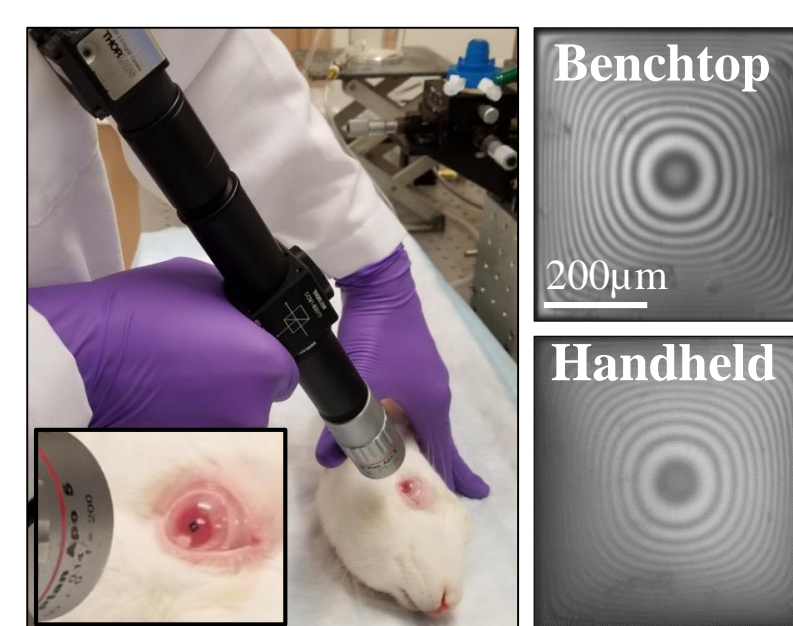
The response of the sensors was characterized using an artificial anterior chamber (Katena) to simulate the pressure condition in the eye. Interference fringe patterns were obtained as a function of the applied pressure and captured by the CMOS camera for analysis. A custom-made image processing algorithm was developed in MATLAB software to analyze the fringe data.

Ex-vivo Study

The sensor was integrated onto two types of intraocular lenses and surgically implanted into a rabbit eye using standard cataract surgery procedures. The results show that the intraocular pressure measurement system has a sensitivity of 22 nm/mmHg and an accuracy as high as ± 0.5 mmHg post implantation.



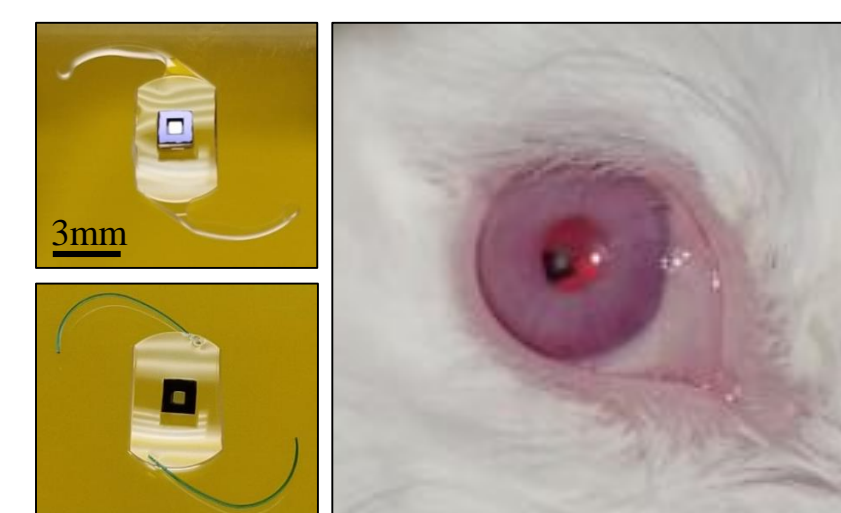
Hand-held Reader



To demonstrate the feasibility of the system for point-of-care applications, the benchtop microscope set-up was replaced with a portable hand-held reader. The hand-held reader with a CMOS camera attachment can be directed towards the sensor implanted in the rabbit eye. The same fringe pattern can be observed in both the benchtop and the hand-held device, indicating the successful use of a portable readout system.

In-vivo Study

In-vivo study is currently in progress. Sensors were integrated onto IOLs with reduced foot print to minimized surgical risk. The goals of the study are: (1) evaluate the biostability and biocompatibility of the sensor and (2) investigate the feasibility of the hand-held reader in a clinical setting by integrating it with a standard slit lamp.



Conclusion

Overall, our results show a very promising approach to help monitor eye pressure in glaucoma patients. As a patient point-of-care technology, the proposed approach will enable patients to obtain accurate and more frequent measurements of their eye pressure at the convenience of their home. Frequent measurement data will equip ophthalmologists with the information necessary to make timely therapeutic interventions and improve treatment plans to preserve vision of glaucoma patients.

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