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Multipurpose integrated active contact lenses

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Electronics, sensors, and communication capabilities will all be embedded in future contact lenses, presenting new opportunities in applications ranging from medicine to virtual reality.

Over the last few decades, conventional contact lenses have been used to correct vision. Advances in manufacturing have changed the lens material: first from glass to the polymers used in gas-permeable contacts, and then to the current highly engineered hydrogels used in soft contact lenses. Recent advances in nano and microfabrication—enabling the construction of exceedingly small electronic, photonic, and sensing devices—promise to transition contact lenses to the next level of sophistication by turning them into functional microsystems. In particular, the promise of integrating display or sensing components onto a contact lens will offer a venue for the construction of novel devices.

For example, consider the construction of a contact lens that incorporates a see-through display that is both remotely powered and controlled via a wireless link. The display resolution may be as low as a single pixel or as high as is technologically feasible: low-resolution displays may find applications in gaming or aiding the deaf to receive information in an expedient fashion, whereas those with high-resolution may find application as substitutes for mobile phone or PDA displays. An intriguing application is augmented reality, in which a computer-generated image is super-imposed onto the that from the outside world. This may find applications in gaming, training, and manufacturing.

It is also interesting to note that live cells cover the surface of the eye. These cells are in indirect contact with blood serum, and thus many biomarkers of interest that are found in the blood may also be detected in tear films: close correlation between blood-serum tear-film levels has already been established for many molecules including glucose. A contact lens that incorporates a set of biosensors and can continuously monitor the biochemical environment of the surface of the eye will provide an invaluable tool for monitoring a person's health status. This

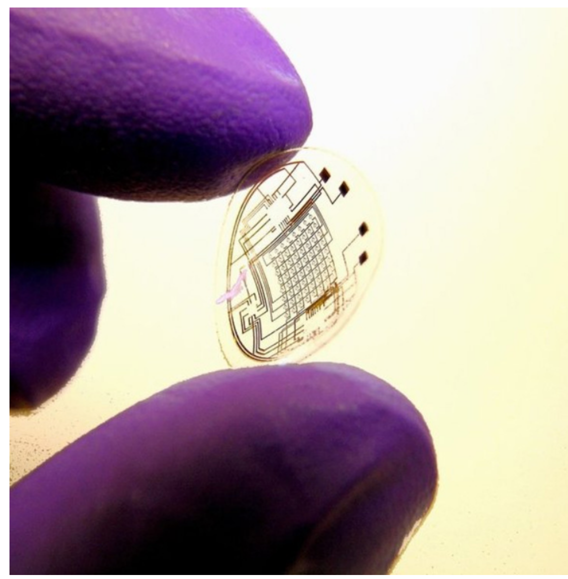

Figure 1. *A University of Washington researcher holds a contact with embedded metal interconnects.*

monitoring can be conducted in a completely non-invasive fashion and will allow access to a data collection ability that has been unavailable to the medical community.

The functional contact lens, incorporating a display or a set of miniature biosensors, is a multifunctional microsystem that requires the integration of a number of functions and components. Various units including power harvesting, antenna, wireless data transmitter/receiver, display control circuit, optoelectronic display pixels, biosensors, and sensor read-out circuits must be integrated onto a flexible transparent thin plastic substrate to form the complete system. Although the microelectronics industry is capable of producing each of the above sub-systems, it is significantly less capable of integrating them to form a functional system.

During the past few years, our group has developed a set of micro-manufacturing processes, based on self-assembly, that enable the integration and construction of a complex multifunc-

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tional microsystem on an unconventional platform such as the contact lens discussed here. Self-assembly is an omnipresent process in nature that contributes to the construction of complicated structures, devices, and systems across the size scale in the biological domain. In a self-assembly process, unlike a manual or a robotic one that may take advantage of top-down supervision, various parts of the system spontaneously find the right location and bind to complete the structure.[1] We have been developing processes to make micron-scale components such as silicon transistors,[2] light emitting diodes (LEDs), and detectors[3] that can be mass-produced and induced to participate in a self-assembly procedure. Using the self-assembly process, we have been able to demonstrate that single crystal silicon circuits and compound semiconductor optoelectronic devices such as LEDs can be integrated onto thin flexible plastics and properly operated.

Self-assembly is a key technology necessary to construct the contact lenses discussed above. Recently, we have been able to show another key technology necessary to build a functional contact lens. In this work,[4] we demonstrated how micron-scale metal interconnects can be incorporated onto a thin flexible plastic substrate (see Figure 1), how the structure can be encapsulated in a biocompatible polymer, and how the encapsulated structure can be micro-molded and polished into the shape of a contact lens. We have tested these lenses for up to 20 minutes on live rabbits and have not observed any adverse effects.

In summary, many of the key technologies necessary to build functional contact lenses have been already demonstrated. Specifically, our group has been able to show that micron-scale functional devices (electronics, optoelectronics) can be made in incompatible microfabrication processes and subsequently integrated onto plastics with self-assembly. All the metal structures necessary for building an interconnected system have already been constructed on a contact lens and tested for safety. We have also demonstrated the construction of a number of micron-scale bio-sensors that can directly convert the presence of a biomarker to an electronic signal. The next challenge will be to integrate all the above functions and yield the first fully functional and stand-alone wireless contact lens. The day that such a device can be demonstrated may be much nearer than was imagined even a short while ago.

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