

# Artificial Retina: a Biocompatible Retinal Prosthesis

A retinal prosthesis co-developed by LLNL can provide at least partial sight to blind persons—even those who have been sightless for decades.

Millions of people worldwide suffer from ocular diseases that degrade the retina, the light-processing component of the eye, causing debilitating blindness. This sad fact is made more sobering when we consider that as our population continues to age, the number of Americans blinded by conditions such as age-related macular degeneration (AMD) and retinitis pigmentosa (RP) will increase. Fortunately, advanced technology is offering real hope to many who are or will be afflicted with blindness. A team of Lawrence Livermore National Laboratory (LLNL), four other national laboratories, four universities, and Second Sight<sup>®</sup> Medical Products, Inc., has developed

a long-term retinal prosthesis that can function for years inside the harsh biological environment of the eye, restoring partial sight to those who may have been blind for decades.

In a human eye, light enters through the pupil, passes through the retina, and stimulates a layer of photoreceptor cells. The healthy human retina contains approximately 100 million photoreceptors. These and other specialized cells convert the optical signals into electrical signals that are processed and then transmitted to the brain, which interprets them as a visual image. Diseases such as AMD and RP destroy many of the photoreceptors, causing



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blindness. To restore sight, the Artificial Retina system converts images from a digital camera into controlled electrical impulses that can stimulate the retina's remaining specialized cells, thus taking the place of the destroyed photoreceptors (Figure 1).

The Artificial Retina system consists of a tiny video camera and transmitter mounted in sunglasses, a visual processing unit (VPU) and a battery pack worn on the belt that powers the entire device (Figure 2), and a retinal implant that stimulates the retinal tissue (Figure 3). LLNL contributes three major components for the Artificial Retina implant: a thin-film electrode array

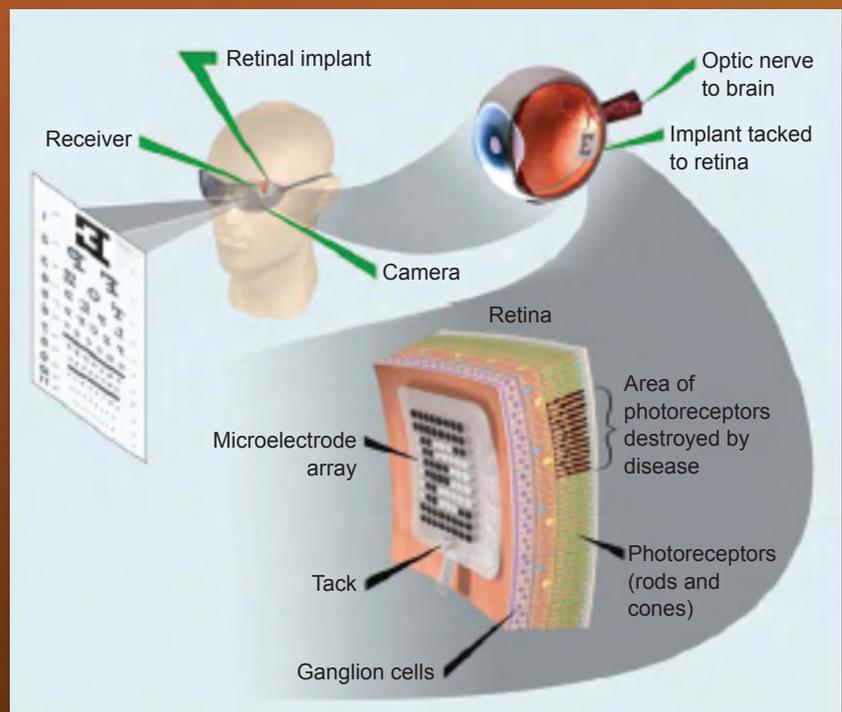


Figure 1. A schematic overview of the Artificial Retina system.



**Figure 2.** (a) The visual processor unit and the glasses with the embedded video camera. (b) A person wearing the visual processing unit and the glasses.



**Figure 3.** An overview of the 200+ electrode Artificial Retina implant. The thin-film electrode array is at the left end of the device, and the biocompatible electronics package is at the right.

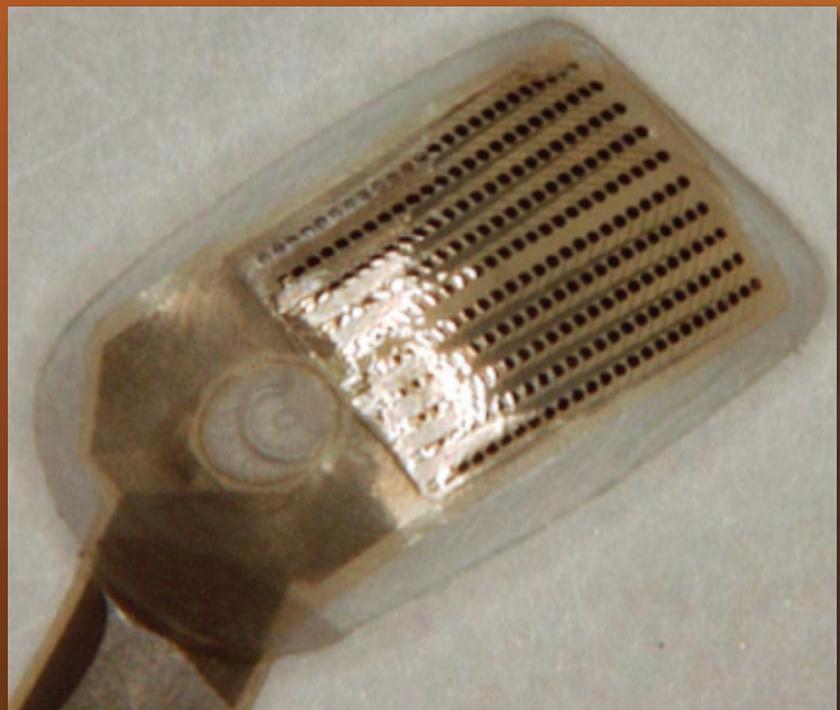
that contains the neural electrodes; a biocompatible electronics package that contains the electronics for stimulating the retina; and an ocular surgical tool that will enable the insertion, attachment, and reinsertion of the thin-film electrode array. LLNL is also responsible for the system integration and assembly of these components to fabricate the complete implantable Artificial Retina system.

To develop neural electrode arrays with sufficient pixels to generate useful vision, a scalable approach had to be used. LLNL made the development process more economical by leveraging batch fabrication technologies from the semiconductor industry. In particular, photolithographic technology, thin-film metalization, reactive ion etching, and electroplating were required to fabricate these neural electrode arrays

since their critical dimensions are on the order of micrometers. In addition, these thin-film electrode arrays were required to conform to the complex curvature of the retinal tissue. This requirement necessitated that the electrode arrays be fabricated on flexible polymers. Since these polymers are not typically used in the semiconductor industry, new technology and processes were developed using existing semiconductor equipment. These technologies enable the production of low-cost, batch-fabricated, high-density thin-film electrode arrays (Figure 4).

The Artificial Retina's biocompatible package contains the microelectronics required to stimulate the neural tissues as well as demodulate the radio frequency power and telemetry signals sent from the external camera and visual processing unit. It was particularly

challenging to develop a biocompatible package that (a) was an order of magnitude smaller in volume than existing implantable medical packages and (b) increased the number of electrical feed-throughs required for communication to the thin-film microelectrode array by several orders of magnitude. Another challenge was that the compact size of the electronics package made it difficult to mechanically and electrically interconnect the microelectronics inside. The biocompatible electronics package also must withstand the harsh in-vivo environment within the human body for more than 10 years. To achieve this time span, the package had to be hermetic, *i.e.*, prevent all transfer of moisture or gases between the volume inside the package and the human body. In conjunction with Second Sight® Medical Products, Inc., LLNL has developed the fabrication



**Figure 4.** Close-up of the 200+ electrode array, which is attached to the retinal wall. This version should enable patients to recognize faces. Additional research and development will produce Artificial Retinas with 1000+ electrodes, which will provide better facial recognition and could enable reading.



**Figure 5.** Overview of the new ocular surgical tool required for retinal prosthesis removal and replacement. This ocular surgical tool is designed to fit onto a standard surgical handle.

and assembly technology needed to satisfy these requirements.

LLNL also designed a technology to remove and replace the existing thin-film electrode arrays. This technology makes it easier for patients to upgrade to newer versions of the Artificial Retina as they become available. For example, a 60-electrode Artificial Retina can be removed and replaced with a 200+ electrode version. We developed an ocular surgical instrument (Figure 5) that can be used to insert and remove the thin-film electrode array. This ocular surgical tool is used to place the thin-film electrode array onto a traditional retinal tack, or to remove it from the retinal tack.

System integration for the Artificial Retina involved developing high-density electrical interconnects between the thin-film electrode array and the biocompatible electronics package. These high-density interconnects must be insulated with a non-conductive film to prevent moisture, ionic, and biological contamination from causing device failure. Again, the density of electrical interconnects was

at least an order of magnitude greater than existing technology. Special packaging technologies were developed to accomplish the electrical and mechanical interconnect between the electronics package and the thin-film electrode array.

The Artificial Retina is the only retinal stimulator currently undergoing large-scale, long-term (chronic) clinical trials. It is also the only retinal stimulator with a fully portable external system and an implant that can withstand daily use for many years. Patients in clinical trial use the Artificial Retina systems outside clinical settings at home and in public venues. In contrast, retinal stimulators developed by other groups have been used only for short-term research that restricted subjects to a clinical setting. In addition, other retinal stimulators have not demonstrated long lifetimes. The Artificial Retina is designed to last in excess of 10 years with daily use.

By increasing the number of channels by 10 times and decreasing its size by 10 times, the latest version of the Artificial Retina has 100 times greater

channel density when compared to state-of-the-art commercialized neural stimulators such as cochlear implants. This achievement in implant design is a quantum leap in the implantable medical device industry and will enable a new generation of biological interface systems to be developed. Recognizing its significance, in 2009 R&D Magazine awarded the Artificial Retina technology not only a prestigious R&D 100 award, but also the Editors' Award, the utmost achievement in developing new technology.

The research and development of the long-term interface represented by the Artificial Retina challenges the limits of engineering, physics, chemistry, and biology. The successful integration of these profoundly different elements (biological tissue versus electronic and mechanical systems) has the potential to usher in a new era of sensors and actuators, not only for biomedical applications but also for a wide range of hybrid surveillance systems, including environmental sensors, and for plant and bacteria studies.