I-CEE: IKVAV — Scaffold Center-Surround Eyesight Enhancement

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ABSTRACT

I-CEE (IKVAV-Scaffold Center-Surround Eyesight Enhancement) employs advances in ophthalmology and material science to treat age-related macular disease and retinitis pigmentosa. I-CEE has a filter, a photovoltaic mosaic layer, and a scaffold of the pentapeptide IKVAV. The filter models the Color Filter Array 2.0 (CFA2) and consists of 1 million units compacted into one squared centimeter. Photovoltaic cells coated in different-colored filters are arranged to support the center-surround for edge detection and contrast enhancement. An IKVAV scaffold provides a base for the photovoltaic cells and aids in neural growth. The distance conserved using retinal migration will minimize the energy lost and the heat generated when the impulse travels to the neurons. Only a specific range of wavelengths is allowed past the filters to reach the photovoltaic cells. The artificial impulses stimulate bipolar cells, which can sort the multiple signals to send to the brain for interpretation.
PRESENT TECHNOLOGY

Recently approved by the Food and Drug Administration was the Argus II Retinal Prosthesis System (Argus). It serves as a substitute for defective photoreceptors and provides sight to those suffering from retinitis pigmentosa and macular degeneration. A video camera in a pair of sunglasses transmits images through a wire in the frame of the glasses. The wire is connected to a video processing unit, which converts the image into 60 pixels. The signal is sent by the unit to an antenna on the glasses, where it is transmitted to a receiver on a scleral buckle wrapped around the eye. The signal then moves to the retina on a 60-wire cable, one for each pixel, with each wire connected to an electrode on an electrode array. The electrodes then stimulate the ganglion cells to produce electrical signals that are sent to the brain via the optic nerve.

The Argus system produces only fuzzy black and white images that allow individuals to perceive basic shapes. For instance, the image below is a sailboat. The individual’s ability to see clearly is limited by the number of electrodes on the array.

Figure 1: Sailboat

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1Greer, Cynthia and Tom Avril. "Light for the Blind."
The current thin-film photovoltaic cells available are amorphous silicon cells. As with many thin-film solar cells, amorphous silicon cells are not very efficient and are costly. Mixed with hydrogen, this solar cell is commonly used for small devices, like watches or calculators. Unfortunately, amorphous silicon degrades easily in direct sunlight and do not have a long lifespan.

HISTORY

In 1956, Australian ophthalmologist Graham Edward Tassicker experimented with one of the earlier types of retinal prosthesis by implanting light-sensitive selenium cells in the retina. Nearby undamaged cells were stimulated by electrical currents that were generated by the conversion of light in the cells. He expected blind patients to be able to recognize light and regain some of their vision. The idea of inserting an electrical stimulating chip into the retina was crucial to the development of retinal prosthesis.

In the 1960s, Giles Brindley developed a method to restore some vision by implanting 80 electrodes into the visual cortex. Each electrode was wired to a radio receiver placed under the scalp. Some patients reported that they saw phosphenes (flashes of white light patterns). There were concerns about the invasive implants involved and he stopped his work in visual prosthesis.

In the 1980s, William Dobelle furthered the concept of stimulating the brain. He used a camera to transfer the images into electrical signals that travel to a processor on the belt of the patient. The signal then travels through a cable to the skull where it stimulates electrodes attached to the surface of the brain. Most of his patients’ vision progressed and they were able to see the contour of objects.

In 1986, Michelson wired electrodes to a photosensitive device embedded in the retina. The device is powered by another circuit through wave frequency induction. Limitations exist due
to the possibility of it causing retinal trauma; the size of the eye must also be taken into account. In addition, if the patient has cataracts that interfere with vision, those must be taken care of separately. As a result of these limitations, the Michelson ‘93 device simply tunes the frequencies to an acceptable voltage range the neurons can accept.

In 1998, the Second Sight Incorporation was founded by Alfred Mann. Its first project was Argus 16, which was tested on six patients in 2004, who afterwards were able to detect light, motion, and the general shape of discrete objects. The basic format of Argus 16 is similar to that of Argus II, the difference being the number of electrons.

Although there is progress in the treatment available to blind patients, there are still problems with Argus II, including the inability to restore color vision and the poor resolution it provides. The Centers for Disease Control and Prevention (CDC) estimate that by 2020, 2.95 million Americans will have impaired vision caused by AMD. With technological advancements, Argus II can be further improved to give the patients a vision as clear and as colorful as that of anyone else. That is our goal for the future. That is our vision.

FUTURE TECHNOLOGY

I-CEE is a retinal prosthesis system made up of three components: a color filter, a photovoltaic cell, and a scaffold created by the pentapeptide IKVAV.

The color filter found in I-CEE utilizes the filter pattern discovered by John Compton and John Hamilton in 2008; it is more sensitive than the long-standing Bayer filter pattern.
The advantage of the Color Filter Array 2.0 (CFA2) is its use of panchromatic filters, which allow the passage of white light. Luminance is the intensity of light that is allowed past the filter and accounts for the details of the image. In the Bayer filter pattern, half of the array is made up of green filters, so most of the white light is absorbed by them. The more sensitive panchromatic filters in the CFA2 allow more light to pass through to capture a high-resolution black-and-white image base. The better sensitivity of CFA2 reduces blurring and noise. The new algorithms that have been implemented in the CFA2 provide superior edge detection, minimizing the amount of color bleeding. The contrast is achieved through the application of center-surround antagonism.

I-CEE utilizes the CFA2 pattern for the positioning of color-filtering photovoltaic cells that converts photons into electricity. Since individual photovoltaic cells are under each filter, photon-electrical conversion for each CFA2 unit is more efficient. Solar cells are made up of semiconductor materials; in I-CEE, silicon is used. Semiconductors are transition metal insulators that have been turned into conductors through doping, a process where the semiconductor element is combined another element. The resulting conductor comes in two forms: n-type and p-type. In n-type doping (negative type), phosphorus or arsenic (each with five valence electrons) is added to silicon. Four of the valence electrons

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2 Compton, John, and John Hamilton. "PluggedIn - Color Filter Array 2.0."
3 "Molecular Expressions Microscopy Primer: Physics of Light and Color - Solar Cell."
from phosphorus or sulfur bond to the four valence electrons in silicon; the remaining single valence electron from either phosphorus or sulfur moves freely and creates a negative charge. In p-type doping, boron or gallium is added to silicon; both have three valence electrons. Holes are formed where the fourth silicon valence electron has nothing to bond to. The photovoltaic cell consists of a p-type layer stacked on an n-type layer, creating a thin wafer. Between the two layers is a junction that acts as an electric field for moving electrons. The impact of a photon displaces electrons in both layers and enters the junction. The movement of electrons generates electrical signals that are ultimately interpreted by the brain.

Beneath the photovoltaic layer lies a constructed scaffold created with the pentapeptide IKVAV, a minute constituent of laminin. Laminin is a glycoprotein found in the cytoskeleton of cells. It promotes cell adhesion and growth and helps link the eye’s natural system to I-CEE. The

*Figure 4: Laminin*  
LIKAV used in I-CEE is arranged in a frame for each filter. It allots areas for the dendritic growth of bipolar cells behind the fovea. Each bipolar cell can receive signals from multiple photovoltaic cells, but the strongest signal is carried through. The direct contact between the solar cells and the bipolar cell eliminates the need for the signal to travel the excess distance. In addition to preventing detractions that may alter the perception of the image accurately, less heat is generated.

From the bipolar cells, the electrical signal travels to the ganglia and the natural biological pathway of optical signals ensues. The photovoltaic cells act as photoreceptors in converting white light into electrical signals. These electrical signals are then perceived by the bipolar cells;
since one bipolar cell’s dendrites may occupy multiple areas in the scaffold, the receptive fields of color may overlap, much as they do in the natural human eye. A cell’s receptive field is defined by the organization of the bipolar cells and the ganglion cells in such a way that each cell responds to a small circular patch of photoreceptors. The receptive fields of the retinal ganglion cells consists of a circular central area and a surrounding ring. The center area and its surround tend to cancel each other’s activities. The two basic types of fields are on-surround /off-center/ and off-center/ on-surround. When light falls upon the center on a on-center ganglion cell, the firing rate increases; when light falls upon the surround area of this ganglion cell, the level of activity in the cell decreases. When a light large enough to span over the center and the surround, the level of activity will decrease. The opposite will occur with the situations previously mentioned for an off-center ganglion cell.

Figure 5: Receptive Fields

BREAKTHROUGHS

Filter Material

The problems I-CEE faces are predominantly in finding, creating, and producing materials that are cost-efficient. The Color Array Filter 2.0 is currently employed in new models of

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KODAK cameras, but it is difficult to assess the changes that the filter must undergo before it is safely dispatched into the damp environment of the inner eye. Additionally, the filter material must be molecularly compatible with the surface of the photovoltaic cell layer to prevent any slips or displacements that may occur from movement. Another option available is to identify an adhesive that may be safe to use within the body; this adhesive must withstand the high temperatures of the eye and endure for an extended period of time.

In the modern era of polymer modification chemistry, color filter patterns are printed onto microchips using photoresistors. The technology now exists to create millions of color filter patterns with a simple downsweep of micron-sized needles into a silicon substrate. Diazonaphthoquinone (DNQ)-novolac photoresists are commonly used to create colored filter arrays. However, the filters created using photoresistors are commonly employed in cameras; the environment supported by the eye may alter the behavior of the filters. Additionally, the effect of heat on the thin filters must be taken into account.

*The Future of Photovoltaics*

While photovoltaic cells are practical for their unique composition consisting of an n-type layer and a p-type layer, the efficiency of photon-electric conversion in each CFA2 cell is hampered by energy loss due to the small distance between the CFA2 array and the ganglions receiving the signal. However, recent research by the National Renewable Energy Laboratory and Boeing-Spectrolab released a new record efficiency of 39% at 236 suns, making the development of I-CEE foreseeable in the near future as technology continues to improve. Current photovoltaic cells are designed only for large amounts of energy uptake for use in solar energy, not for the purposes of I-CEE. As the surface area of the CFA2 array is considerably smaller, less energy loss would occur.
Another barrier to efficiency is the thin material of I-CEE, as the thinner silicon becomes, the less efficient it is. I-CEE would be built with amorphous silicon (a-Si) due to its thin, film-like consistency. It is currently gaining a rapidly expanding market for innovative consumer products such as calculators. Research is being undertaken to improve the stability and conversion efficiency of a-Si modules for better use. Work is also being done to counter the Staebler-Wronski effect, where the model loses conversion efficiency after first being exposed to sunlight.

Despite recent decreases, photovoltaic cells remain expensive to manufacture, especially at a small scale, due to their size. The scale of I-CEE production, though, would be much smaller and allow for cheaper manufacturing. The cost of creating a-Si is considerable also, but declining with improved manufacturing processes that involve increasing the rates of depositing material and packaging to prevent damage from moisture.

CONSEQUENCES

Although I-CEE's immediate impacts are reserved in the field of ophthalmalogy, its implications for the society and economy are significant assessments to acknowledge. By enabling patients with macular degeneration or retinitis pigmentosa to see the world in crisp images, I-CEE allows for a positive change in lifestyle, bringing more freedom and independence to each individual. Without the weight and drag of having to don on the bulky sunglasses and processing box of Argus II, mobility improves comparatively. Since I-CEE operates within the eye, it is undetectable to any spectators; in fact, patients suffering from photoreceptor-related diseases will be indistinguishable from those with natural eyesight, as their abilities expand with the enhanced eyesight they are able to achieve. Allowing many more opportunities to patients aids them in their integration to society and jobs that would otherwise have been unattainable.
Inevitably, the perception of the blind would substantially improve favorably, reducing the stigma and discrimination that may underlie visible disabilities.

The color filters found in I-CEE aid in generating full-colored images that rival those of a modern cameras, due to the specificity of the CFA2 array. In comparison to Argus, which produces only a black and white real-time succession of photographs composed of large pixels, ICEE allows for greater resolution and sensitivity to light. The CFA2 works well in low-light conditions, an aspect that trumps the capability of current bionic eyes.

The photovoltaic cells in I-CEE are inherently processed to use a renewable energy source to form impulses that eventually allow for visual perception. Patients do not need to spend time and money to charge their new eye. I-CEE reduces the risk of potential accidents that may occur from a deficiency in sight. As a result, medical fees and constant returns to the doctor's office are either greatly diminished or eliminated; the cost of health insurance will become more affordable, as fewer people become injured.

However, the initial cost of I-CEE is greater than the cost of its predecessor, Argus, as not everyone would be able to afford the surgery. Like other invasive surgeries, the implantation of I-CEE will have risks involved. There is a possibility of side effects such as eye irritation and infections. The body can also reject I-CEE, which can cause other complications. Even if the body accepts I-CEE after a successful surgery, there is a risk of malfunctions and defects. However, the likelihood of these problems will diminish with further technological development.

**DESIGN PROCESS**

Though Argus allows a significant improvement for the blind, the system only allows the brain to generate a picture that is decipherable only as cubes of white and black. Our goal was to improve the resolution and attain color perception.
The Replacement of the 60-electrode Microchip with a Charge-Couple Device (CCD)

CCDs are digital image sensors made out of plates of silicon dotted with millions of photocells—when these cells are hit by light, electrons are knocked out and gather into cell wells. Electrons that have gathered in the well can be read by applying a voltage. The contents empty out into a belt, row by row, which the CCD converts into a language read by the computer and converted into pixels. With their widespread use in cameras, CCDs as Argus microchips easily became the first idea we looked to develop. It tackled our initial goals: bringing the resolution to new heights and allowing for color. CCDs usually have up to half a million pixels, which are each the size of a few microns; and are able to achieve color images through filters that detect color through the intensity of light. Thus, CCDs are able to provide perception of acute details, modeling the resolution of a photograph.

Despite the effective function of CCDs, vital concerns plagued the viability of inserting it onto the retina. First, a CCD is relatively large, as 4.5 x 3.4 mm microchip is needed to capture a 1.3-million-pixel image, which would functionally be too large to fit into the retina. Second, CCDs in digital cameras are able to afford the heat generated through traveling electricity—in the eye, this heat would damage nearby nerves and cells. Third, the efficiency of CCDs is about 70%, as much of the light is not perceived; it is more sensitive to infrared light than it is to visible light.

Coupling Lasers and a Network of Carbon Nanotubes to Relay Electrical Signals

Rather than tackling the intermediary between ganglion cells and photons, we looked towards an alternative sources of stimulation. Lasers’ ability to stimulate neurons in the brain in prosthetic limbs evoked our interest—would it be possible to directly stimulate ganglion cells? In place of a microchip with electrodes to relay electrical signals, we planned to install a network of
carbon nanotubes onto the retina, which would transmit a laser pulse with an appropriate energy level (our conditions were 1 picosecond pulses at 0.9 mJ/sq.cm because this is the electrical threshold needed to stimulate a neuron). We contemplated using optical fibers to transmit the lasers, but the size of each fiber made the idea an unreasonable option. The carbon nanotube network would form an ultrathin layer over the front of the retinal ganglion cells so that each laser signal transmitted would reach exactly one ganglion, ensuring a high resolution.

The technical areas and implementation measures posed serious problems. First, we were uncertain of the effectiveness of carbon nanotubes in transmitting lasers—even if the process were possible, there was no guarantee of the laser traveling within the tube. Second, despite the rapid cooling property of carbon nanotubes, a warm and salty environment with a lack of a cooling source would increase the risk of intense pulses of light and heat destroying surrounding cells. Third, it became unreasonable to assume the possibility of creating a system that would turn photons into laser signals—small enough to be situated within the eye. Fourth, it was too risky to subject sensitive retinal cells to prolonged exposure to flashes of concentrated light.

**Installing Nano-Antennas to Act as Photoreceptors**

Nano-antennas would be plastered onto the visual cortex, where colored pixels would be converted by an external processing box into corresponding wavelengths, with each antenna reacting and receiving a specific wavelength. Upon contact on the appropriate tip of the antenna with light, an electrical signal would be generated to directly contact the brain, where it would be perceived as an image. Not only would this model provide color images, but a high resolution would be maintained by having all the ganglions stimulated with just a small amount of antennas.

Problems, however, are imminent. First, it is an immense operation to determine the exact location in which to place the nano-antennas. If the electrical signals were not corresponded
accurately, the resulting image would be a visual disaster. It would be dangerous, too, to send
electrical signals haphazardly in such a confined area—the model runs the risk of stimulating
surrounding neurons in the brain. In addition, in order for these synthetic signals to be perceived,
the brain would have to “learn” to read such electrical signals.

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