INTRAOCULAR RETINAL PROSTHESIS TEST DEVICE

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ABSTRACT

There is a growing interest in the development of a retinal prosthesis device based on a number of recent experiments demonstrating human perception of electrical stimulation of retinal tissue with single electrodes. An intraocular retinal prosthesis test device is currently under development at NRL/JHU. The microelectronic device has an image format of 80 x 40 unit cells interfaced to the retinal surface via an array of microwires in a glass matrix. The system architecture and technology development issues are discussed as well as the issue of retinal tissue response. This test device will enable acute human experiments in an operating room environment to demonstrate a massively parallel interface between retinal tissue and a microelectronic array.

PROJECT GOAL AND APPROACH

GOAL

Demonstrate a massive, parallel interface between a 2-D microelectronic stimulator array and neural tissue layers:

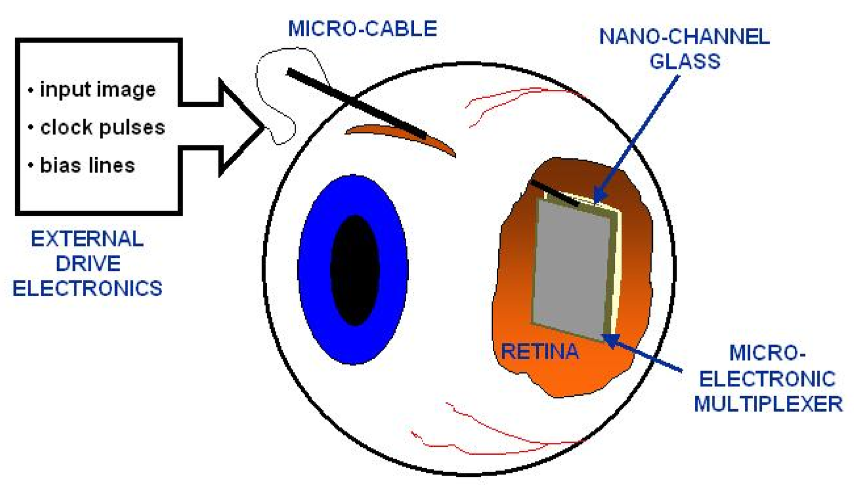
- Array will have 3,200 independent electrodes; update rate of 60 hz
- Input signal can be any complex, spatio-temporal pattern
- Safe neural stimulation techniques will be determined

APPROACH

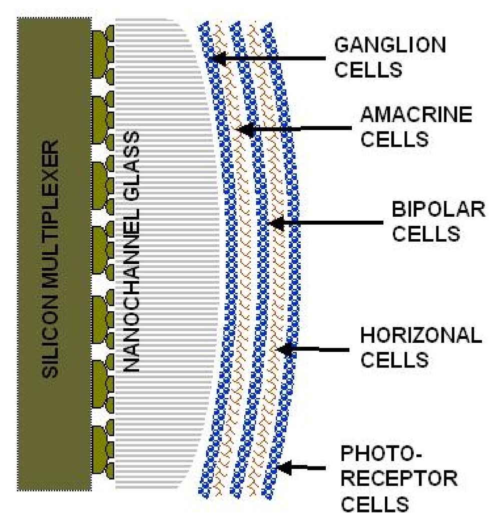
Design and fabricate a retinal stimulator array for testing with blind human subjects in operating room conditions. Design is based on existing techniques:

- Infrared focal plane array multiplexer technology
- Nanochannel glass technology
- Retinal models and realtime image processing algorithms

MICROELECTRONIC STIMULATOR ARRAY POSITIONED AGAINST INNER RETINA



ARRAY AND RETINA IN CROSSECTION



GLASS MICROELECTRODE ARRAYS

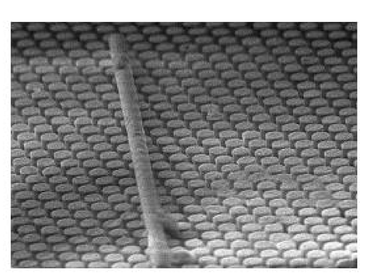
Channel glass technology enables connections to millions of neurons

- Excellent compatibility with biological tissue
- Surface can be made conformal to fit curvature of any neural topography
- Metal can be deposited in hollow channels to provide millions of electrodes
- Microelectrodes offer high resolution interface

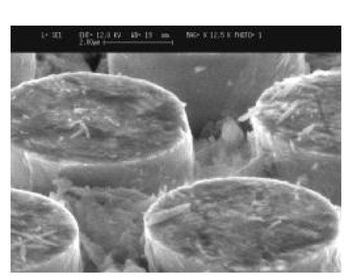
Current Features:

- Small electrodes (diameter of 1.6 - 6 μm)
- Center to center spacing of 2.4 - 9 μm
- Large area arrays of 1 - 5 cm^2

ELECTRON MICROGRAPHS OF CHANNEL GLASS WITH WIRES



Electro-deposited *Ni* wires with glass etched-back



CHANNEL GLASS WIRE ELECTROPLATING

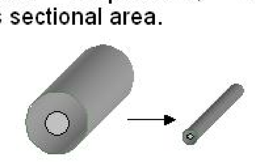
Eight-beaker setup for channel glass electroplating allowing parallel experimentation and production runs. Stainless steel bath at right holds beakers at controlled temperature, each has an individual stirrer. All beakers are computer controlled and monitored via LABVIEW.

NANOCHANNEL GLASS FABRICATION

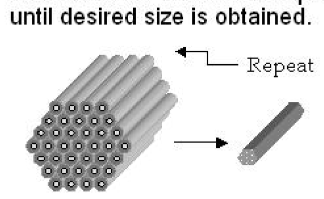
Nanochannel glass is fabricated by bundling composite glass fibers into a desired pattern and drawing the bundle at elevated temperature.

1. Etchable glass rod is inserted into inert glass tube.

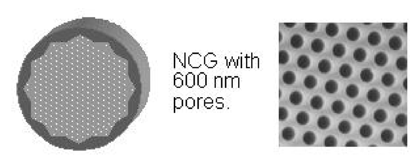
2. Arrangement is drawn at elevated temperature, reducing cross sectional area.



3. Elements are bundled, clamped, and redrawn. Process is repeated until desired size is obtained.

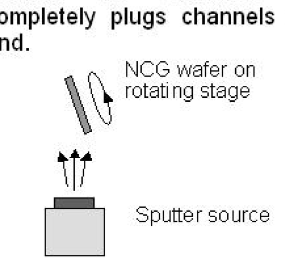


4. Final bundle is fused in a glass cladding under vacuum. Material is then wafered, polished, and etched to expose channels.

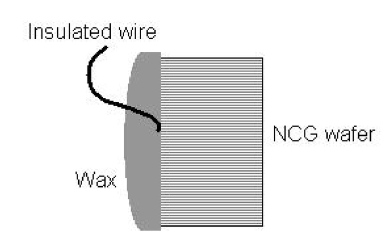


Science, Vol. 258, p. 783 (1992).

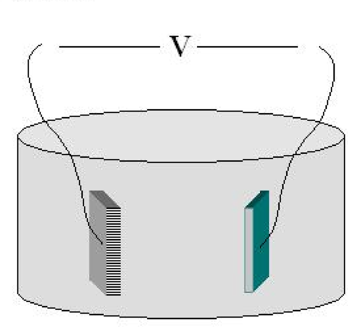
5. Polished and etched NCG wafer is coated on one side with platinum by sputtering at glancing angle to provide an electrode which completely plugs channels at one end.



6. Electrical connection is made to platinum electrode, and back surface is sealed in wax to ensure that plating occurs inside channels at base of electrode.

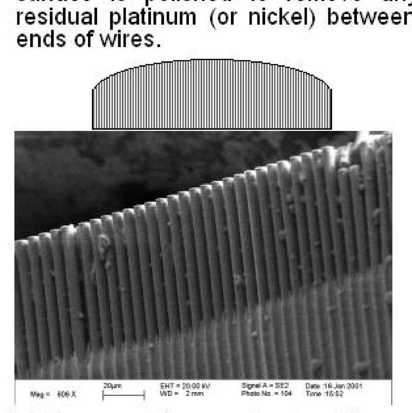


7. NCG wafer is immersed in plating solution along with platinum plate counter-electrode, and plating process is carried out until platinum (or nickel) wires are generated across the full wafer thickness.



Platinum(or nickel) plating solution

8. Wax and wire are removed from NCG wafer. One surface is polished with appropriate ***curvature***. Other surface is polished to remove any residual platinum (or nickel) between ends of wires.

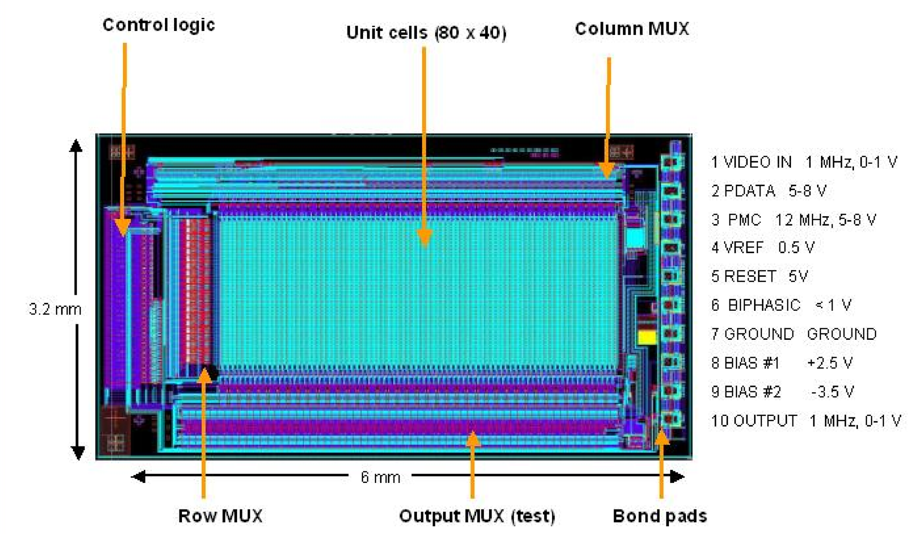


SEM images of long, protruding *Ni* electrodes created with a 10 minute etch in 5% HF- etch depth is approximately 68 microns .

MICROELECTRONIC MULTIPLEXER CHIP

- MULTIPLEXER DESIGN
  - –Chip size is 6 mm x 3.2 mm - format is 80 x 40 unit cells, measuring 36 μm x 50 μm each.
  - –Design was finalized and checked using Cadence LVS and DRC software
- MULTIPLEXER FABRICATION AND TEST
  - –48 chips were fabricated at SuperTex (formerly Orbit) as part of a *Foresight* run.
  - –Post-processing at Raytheon - deposit 20 x 30 μm islands of indium in unit cells
  - –NRL has packaged multiple chips on a standard ceramic carrier for initial electronic test and characterization.

MULTIPLEXER ARRAY FLOOR PLAN

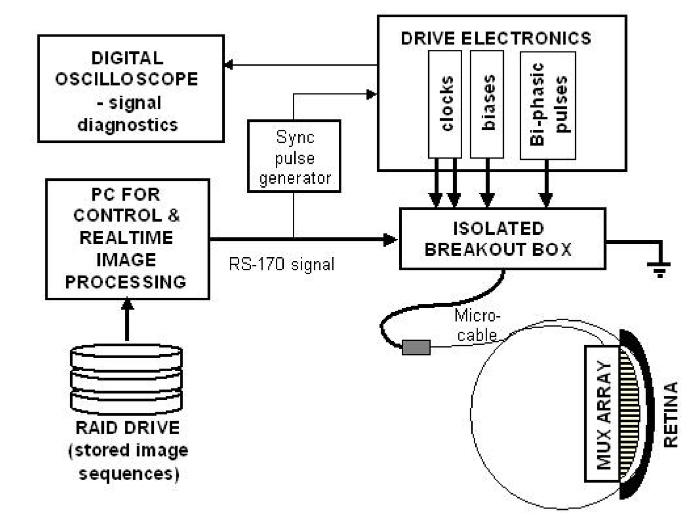


Multiplexer connects thousands of neural sites to outside world via a handful of external leads.

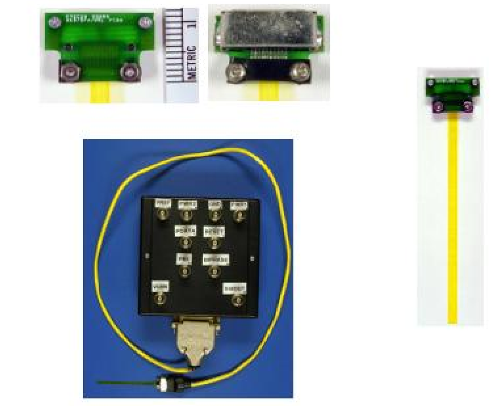
COMPACT DIMENSIONS OF MULTIPLEXER CHIP

Photo showing relative size of silicon multiplexer chip - 6 x 3.2 mm.

ANCILLARY ELECTRONICS

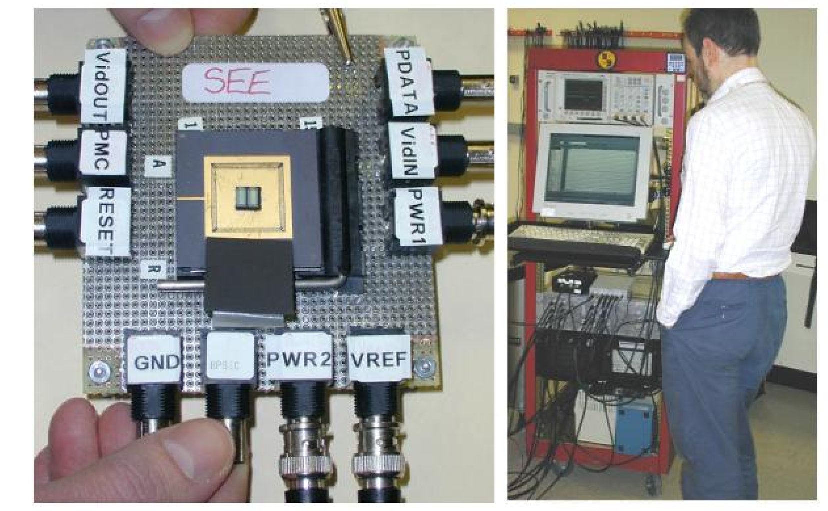


MULTIPLEXER ELECTRICAL CONNECTION

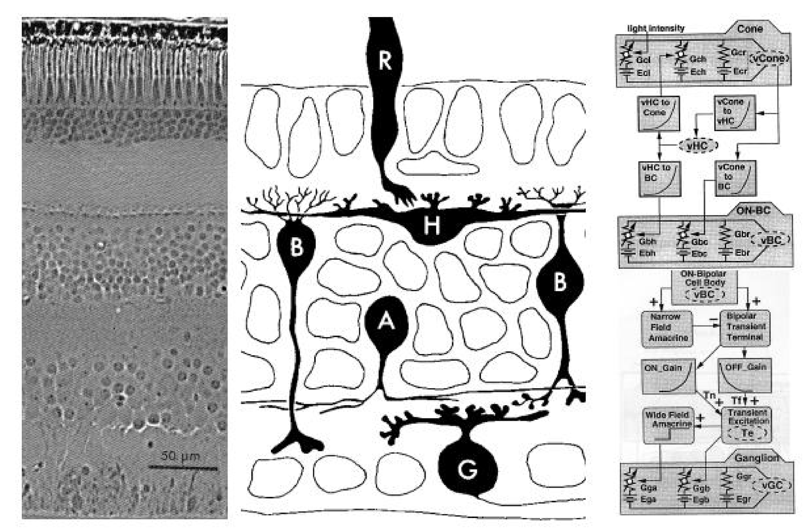


Polyimide microcable shown with custom connector, and interface cable/box. The cable was designed to connect directly to the ten bond pads on the silicon multiplexer chip.

CHIP TESTING / DRIVE ELECTRONICS



MODELING OF NEURAL FUNCTIONS

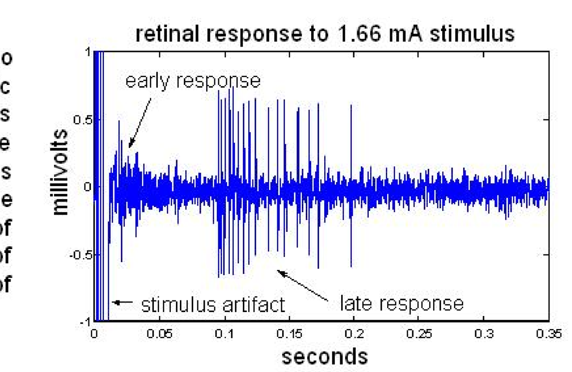


biological tissue | simplified morphology | analytic model

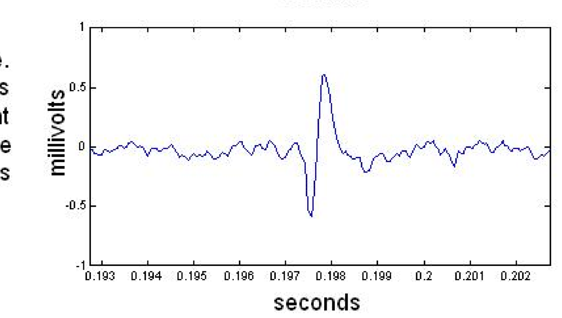
SAMPLE OUTPUT FROM COMPUTER SIMULATIONS OF RETINAL FUNCTIONS

THE RETINAL RESPONSE TO STIMULATION WITH CHANNEL GLASS ELECTRODE.

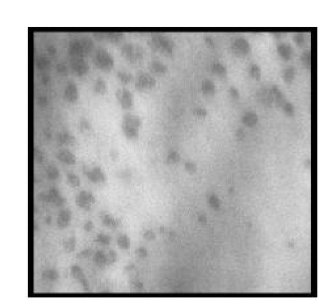
The retinal response to stimulation. A biphasic current pulse was delivered through the nano-channel glass electrode. The pulse consisted of 1ms of cathodic current, 3 ms of zero current and 1 ms of anodic current.



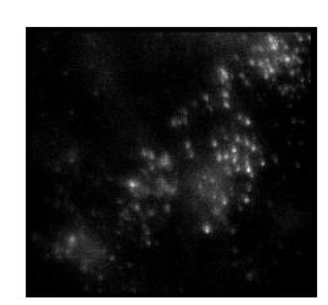
A single evoked response. The 1.66mA of current was delivered via a constant current stimulator. The current density was 0.00065 $\mu A/\mu m^2$.



PLANNED OPTICAL RECORDING OF ELECTRICAL STIMULATION PATTERNS



Transmission image of retina



Fluo-4 calcium dye fluorescence image of retina

SUMMARY

The hope of restoring vision to the blind is now believed to be a real possibility using neural prosthetics. The IRP test device described above is an important step toward demonstrating a massively parallel interface between a microelectronic array and neural tissue. However, many technical problems remain and many engineering issues must be resolved before complete clinical success is achieved. Not the least of these problems will be solving the issues of biocompatibility and the reliability of a device that will be implanted and expected to function without degradation for decades. Ultimately, the true measure of success will be the acceptance of this approach by the blind community. Hopefully this success will parallel that of the cochlear implant that, although initially slow, continues to grow exponentially each year and is now a fully commercialised medical product.

ACKNOWLEDGMENT

Work on an IRP test device is being sponsored by Alan Rudolph who manages the DARPA Tissue Based Biosensors Program and by Joel Davis who manages neuro-biology programs for the Office of Naval Research.

Note: As of September 1, 2001 the Johns Hopkins Collaborators have moved to the University of Southern California, Doheny Eye Institute, Los Angeles CA