**4. TITLE AND SUBTITLE**

Development of an implantable optical neuroprosthetic: System integration and testing.

**6. AUTHOR(S)**

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**9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)**

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**11. SUPPLEMENTARY NOTES**

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**13. ABSTRACT (Maximum 200 words)**

This report contains the final progress report of the project entitled "Development of an implantable optical neuroprosthetic: System integration and testing." We have completed all goals set out in the application. I. We have redesigned and build the microscope body to be lighter weight. II. We designed and build the mounting hardware for attaching the microscope to the head of a rodent. III. We have designed and build the camera head with associated PC boards to house and power the imaging chip. IV. We have redesigned, built and tested a new imaging chip based in silicon and sapphire. The results of this work is presented.

**14. SUBJECT TERMS**

Neuroprosthetic, fluorescent microscope, voltage dye imaging, nervous system, activity monitoring, CNS

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5. Subject Inventions - Required to be Reported by Contractor/Subcontractor:

- **New Haven, CT 06519**
- **200 Congress Avenue**
- **09/10/2007**
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6. Subcontracts Awarded by Contractor/Subcontractor (if none, do not fill in)

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c. Final Progress Report

(1) Forward - None
(2) Table of Contents - None
(3) List of Appendixes - None
(4) Statement of problem studied - Continued development of an optical neuroprosthetic.
(5) Summary of the most important results

I. Redesign of the microscope housing, head attachment ring and objective lens.
In order to bring the microscope closer to functionality we have reduce its size and weight by reducing the material used in the make the microscope housing (Version 3.0). While still using a polyethylene material we redesigned the microscope housing to be more form fitting to the internal elements, reducing the mass of plastic needed (Figure 1). In the new design we also included the necessary orifice size to include the larger (9 mm) low magnification objective lens (ThorLabs) we are currently using. Finally we have begun to develop the design of the head mounting ring (Figure 2). We have developed and built a three part system which includes a ring which is mounted over the craniotomy. This ring is made of stainless steel and is secured to the skull with cyanoacrylic. The ring is used to hold the dye for the staining step and then serves to form a well to hold ACSF once the staining is complete. The second part of the device is a coverslip (green structure in center pan of Figure 2) within a grove in the head mount. This cover is secured to the head ring with a series of tiny (000) screws. Once the mounting plate/ ring and cover are secured to the head, the microscope is lowered down with a mounting ring and attached to the animals head via dental cement. The microscope can then be removed from the pressure fit ring in between experiments.

II. Design and built the camera housing and PC board.
With this version of the microscope (3.0) we have begun to integrate the camera and imaging chip into the microscope. We have designed and constructed a camera housing for the imaging chip we have built.
developed (chip described below). This housing is small, light weight and includes two PC boards, which hold the chip and associated electronics (Figure 3 and 4). The upper board contains the A/D and D/A chips necessary to run the chip. On the upper board is an Omnetics connector (32 pins) to handle I/O for the camera (Violet structure in Figure 3A) and the imaging chip is mounted on the bottom face of the lower board (Purple structure in Figure 3B). The camera attaches by pressure fit to the top of the microscope.

III. Redesigned and built the imaging chip using silicon on insulator technology.
The original design of imaging chips 1.0 and 2.0 used silicon on sapphire technology. The electrical design and circuitry of those chips were functional and meet specifications sampling at the desired rate. However, the spectral sensitivity of the chip was decidedly blue shifted with little sensitivity in the red. This was an unfortunate and wholly unexpected characteristic of this novel semiconductor material. For version 3.0 we chose the standard semiconductor material silicon and used the same differential imaging design of chips versions 1.0- 2.0 (Figure 5). We have just received the new chip and are now evaluating it. Currently it has all the characteristics we sought in an imaging chip for use in this microscope and has met all design characteristics. The chip’s energy usage is extremely low (< 5 mW) and it has a high signal-to -noise ratio at

![Figure 4: Microscope 3.0](image)

**Figure 4: Microscope 3.0**
to the top of the microscope.

![Figure 5: CMOS imaging chip. A) The pixel used in our design. Each pixel contains two storage capacitors that are used to store subsequent frame values and perform intensity difference computation. The photodetector area is 75 μm x 75 μm. B) Our system is composed of 32x32 pixel array. The scan shift registers are used to address each pixel. A global differential amplifier subtracts two subsequent pixel values. The sensor can also report intensity frames (no subtraction). This image sensor is fabricated in a bulk CMOS 0.5 μm process. C) CAD drawing of the 32 X32 CMOS imager chip as delivered to the foundry.](image)
low light (70-75 dB at various light intensities; see Figure 6A). We were hoping for SNR of 55 to 72 dB the large immobile RedShirtImaging, LLC NeuroCCD has a SNR of 85 dB. We are well within the design specifications at low light we sought. This shows the leakage of our storage capacitor (used for frame differencing mode). The storage capacitor leaks 410 μV per second, which means at 1000 fps (1 ms integration time), it should leak 410 nV, well within our noise levels (Figure 6B).

We next collected images from the chip using the normal (Figure 7A) and on-chip frame subtraction mode Figure 7B). Image collection was performed using new Windows-based imaging software developed for the project that allows us to interface with the chip directly using a USB 2.0 board. We captured an image of a hand with the fingers moving rapidly and the camera produces the difference image of only the movement. This interimage subtraction is the novel design characteristic of this chip and is functioning as designed.

Figure 6: Imaging chip noise and holding capacitor leak characteristics

Figure 7: Images from new VSDI chip