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(DURIP-09) Near-Field Scanning Optical Microscope/Atomic Force Microscope with Broad-Band Source for Study of Optical Metamaterials and Nanocircuits

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**14. ABSTRACT**

With the DURIP Grant Number FA9550-09-1-0448 we purchased a Nanonics MV-4000 Near Field Scanning Optical Microscope (NSOM) and a Fianium SC450-6 Super Continuum laser.
Conventional far-field microscopy is limited by the diffraction such that all optical information about features smaller than one-half the wavelength is lost between the sample being investigated and the eye of the observer. This can be likened to the difficulties inherent in trying to understand the layout of an electronic circuit by examining its radio frequency radiation pattern with an antenna from across the room. However, this does not mean that these features do not affect the fields locally. Just as one can understand the local voltages with a voltage probe and oscilloscope, using an NSOM, we can understand the local optical fields using a small aperture on the end of an optical fiber and an avalanche photodiode (APD). While this is a useful description of how an NSOM enables near-field microscopy, the analogy is particularly apropos as our goal is to take the powerful modular nature of conventional electronics and move this into the optical domain using through extreme miniaturization and techniques born out of metamaterials.

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Final Report for the DURIP Grant Entitled

# *Near-Field Scanning Optical Microscope/ Atomic Force Microscope with Broad-band Source for Study of Optical Metamaterials and Nanocircuits*

Grant Number FA9550-09-1-0448

Duration: June 1, 2009 till May 31, 2010

*PI: Nader Engheta*
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*Postdoc: Brian Edwards*
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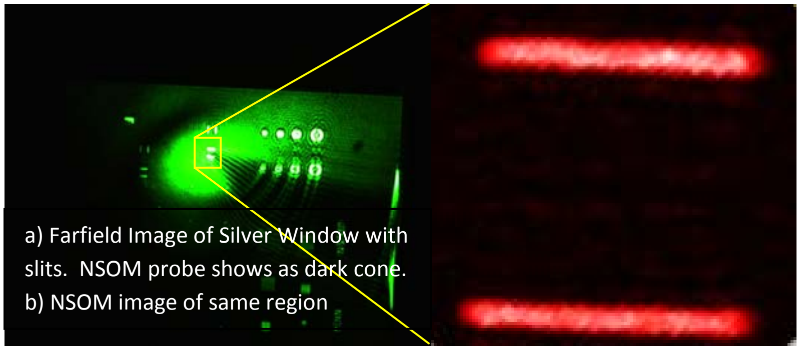
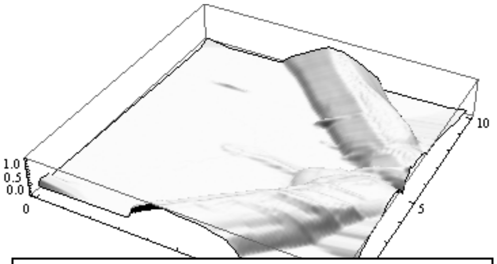
*Philadelphia, Pennsylvania 19104*

With the DURIP Grant Number FA9550-09-1-0448 we purchased a Nanonics MV-4000 Near Field Scanning Optical Microscope (NSOM) and a Fianium SC450-6 Super Continuum laser.



a) Farfield Image of Silver Window with slits. NSOM probe shows as dark cone.
b) NSOM image of same region

Conventional far-field microscopy is limited by the diffraction such that all optical information about features smaller than one-half the wavelength is lost between the sample being investigated and the eye of the observer. This can be likened to the difficulties inherent in trying to understand the layout of an electronic circuit by examining its radio frequency radiation pattern with an antenna from across the room. However, this does not mean that these features do not affect the fields locally. Just as one can understand the local voltages with a voltage probe and oscilloscope, using an NSOM, we can understand the local optical fields using a small aperture on the end of an optical fiber and an avalanche photodiode (APD). While this is a useful description of how an NSOM enables near-field microscopy, the analogy is particularly apropos as our goal is to take the powerful modular nature of conventional electronics and move this into the optical domain using through extreme miniaturization and techniques born out of metamaterials.



AFM image of direct write LASER polymerized photoresist.

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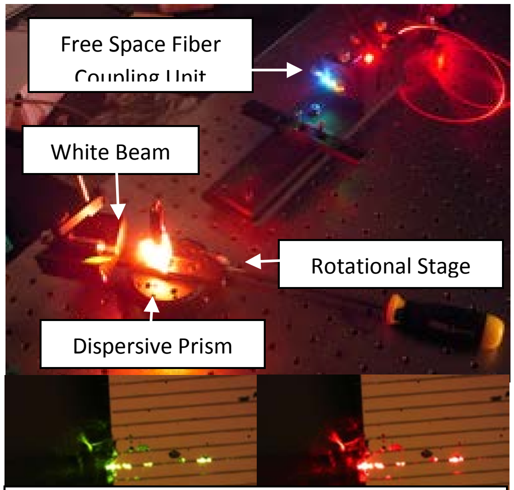
Additionally, NSOMs are also atomic force microscropes (AFM). Since the near fields decay exponentially away from the sample, it is important to keep the probe at a fixed height above the surface. This is only possible using the feedback inherent in an AFM. This provides an independent image topographic image of the sample.



Demonstration of selectable wavelength at point of sample.

Devices such as inductors and capacitors take on their most interesting behavior when examined across different frequencies. One significant disadvantage of an NSOM is the optical throughput. For this reason, lasers are often used to provide the intensities required to generate workable optical signals. However, in this case, the monochromatic nature of a conventional laser is decidedly inconvenient for doing broadband characterization of optical devices. In contrast, a super-continuum laser source takes a conventional laser and amplifies it with distortion continuously until it has completely lost its temporal coherency and becomes essentially optical "static", being broadband and appearing white. However, it remains spatially coherent and can be focused with achromatic optics with the same power as a conventional laser. This laser has on the order of a five milli-Watts of power per nanometer of wavelength. Combining the super-continuum source with a homebuilt monochromator, we can continuously scan the frequency of the optical source while maintaining the same intensity as a conventional laser.

Following one year of ownership of this equipment made possible with the DURIP grant, we have thoroughly evaluated its performance and found it to be perfectly within specifications. We have used the NSOM to map several silver nanowires sent to us by one of our collaborators, and we have also utilized this machine to view the laser focus spot on a substrate in preparation for visualization of the optical field distributions along nanorods. Combined, this equipment yields a system which has enabled us to begin to study the optical nanocircuit elements.