AEgis TECHNOLOGIES

Center for Nanophase Materials Sciences

Nanophotonics and Sensor Development for DoD Applications at the ORNL CNMS

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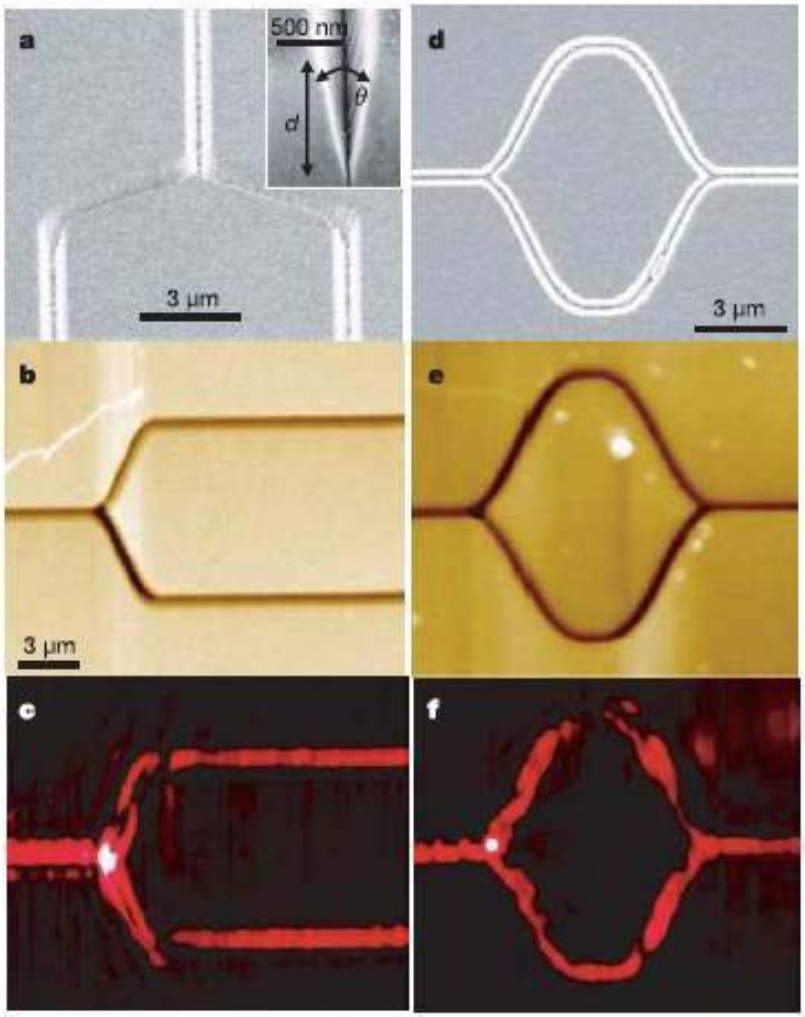
Overview



S. I. Bozhevolnyi, V. S. Volkov, E. Devaux, J.Y. Laluet, and T. W. Ebbesen, "Channel plasmon subwavelength waveguide components including nterferometers and ring resonators," *Nature* ***440, 508-511 (2006) [doi:10.1038/nature04594].***

1. What is AEgis

2. Survey of Current CNMS/AEgis Projects

- **Photonic Crystal Biosensor**
- **Cardio Protein Electrochemical Sensor**
- **Plasmonics**

3. CNMS Positives

4. Suggestions for Industry-Related Enhancements

Corporate Introduction

Center for Nanophase Materials Sciences

About AEgis Technologies

- Provides world-class modeling and simulation technical services, products, and professional training.
- Small Business
- Established in 1989
- Headquartered in Huntsville, AL
- 170+ Employees
- 2005 Revenue $26.5M

Of our 170+ Employees

- 37% have Master's Degree or better
- 63% have Engineering or CS degrees
- 35% have Military Service experience

Relevant Facts

- Recognized three times on INC Magazine's "INC 500" list of the fastest growing privately held companies in America
- Recognized on the *Military Training Technology* Top 100 list of companies that have made significant contributions to the military training industry
- Recognized by the Better Business Bureau for Marketplace Ethics
- Recognized by the Society of Financial Service Professionals for Ethics in the Business Community

Team Members

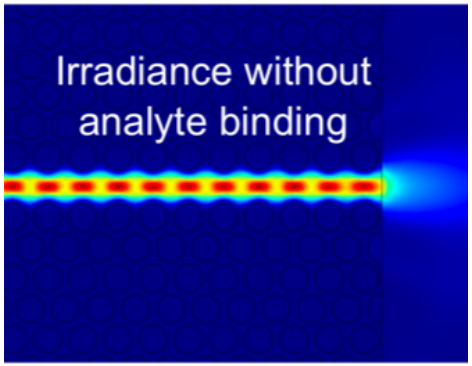
Space and Missile Defense Command

Aviation and Missile Research and Development Engineering Command

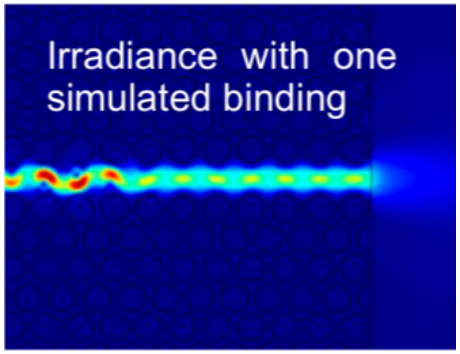
Photonic crystal Sensor Background

- Photonic crystals manipulate the propagation and dispersion of electromagnetic waves in a material

- PCS technology addresses current technology gaps
  - Beginning to transition from laboratory into operational sensor systems
  - Failures attributed to adoption of immature technology
  - Competitive global market



- Examples
  - Integrated optical circuits
  - *Chemical and biological sensors*
  - Active optical components



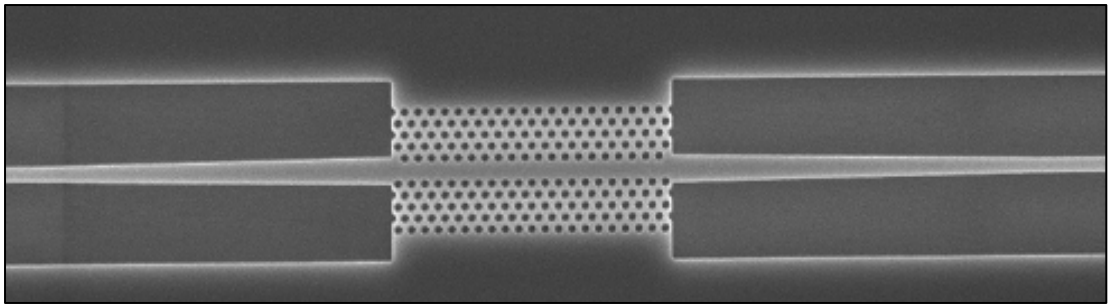
- Biological Sensing with a PCS Transducer
  - Analyte binding changes transmission properties of the PCS
  - Measured spectral shift or intensity drop at target λ
  - Functionalized for selectivity
  - High sensor density possible with multiple channels

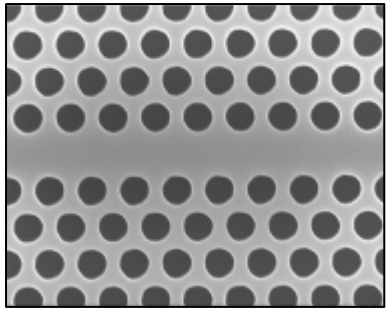
Biological Sensing with a PCS Transducer

- Mode of Operation
  - Liquid or vapor phase sampling medium
  - Analyte binding changes transmission properties of the PCS
    - Can be sensitive to single analyte binding event
    - Measured by spectral shift or intensity drop at a target wavelength
  - Functionalized for selectivity
  - High sensor density possible with multiple channels

- Biosensing applications in homeland security, food safety, health services

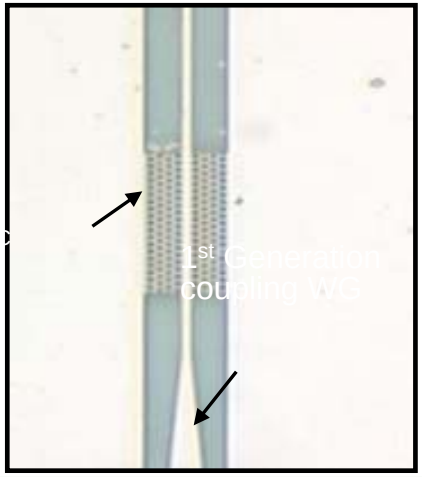
- Developing a sensor with a PBG waveguide indicating analyte binding

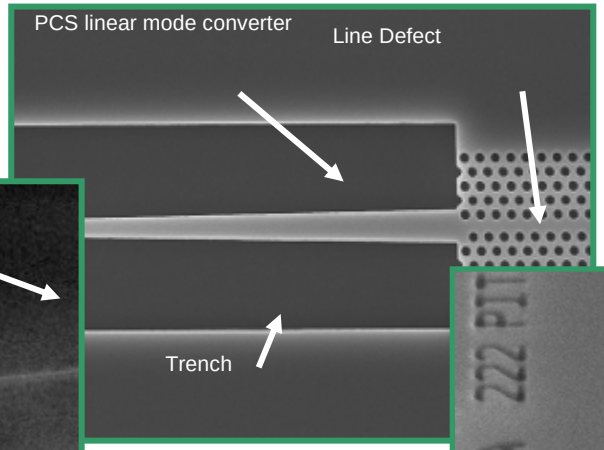


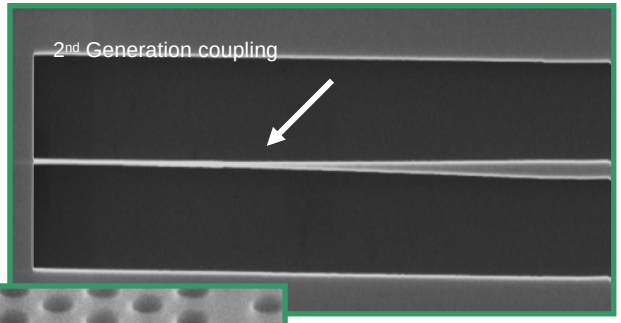


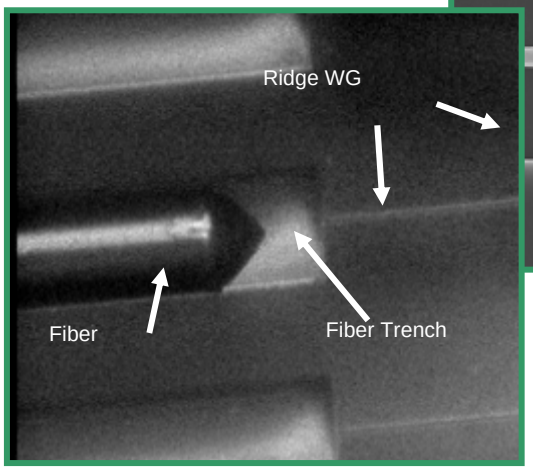
Photonic Crystal Device Images

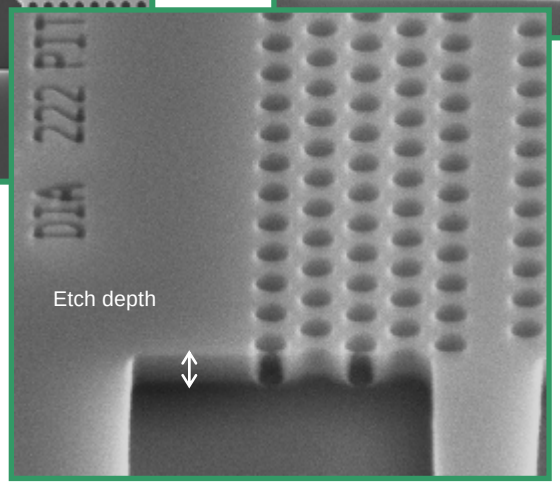
- Fabricated device images collected with SEM and optical microscope
  - PCS devices
  - Shallow Si etch depth
  - Linear mode converters
  - Coupling waveguides
  - Fiber trenches at entrance and exit of PC devices









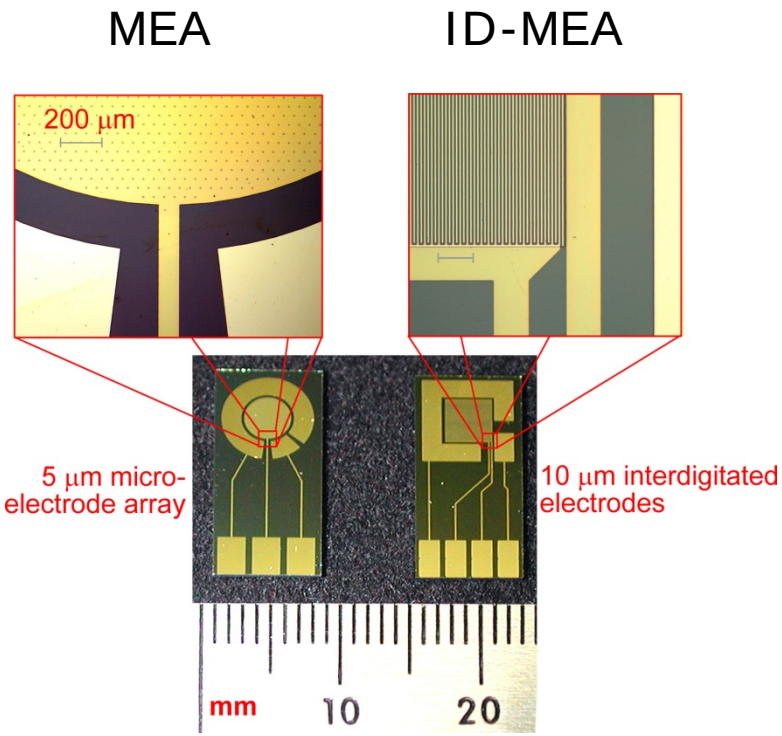


Electrochemical Sensor Development

- Relevance of Electrochemical Sensing
  - High sensitivity and selectivity
  - Detect proteins, enzymes and even select DNA sequences
  - Very small solution volumes
  - Short turnaround time (STAT), Single use, POC testing for bed side analysis
- Objectives of the Project
  - Determine the **limit of feature size** that can be fabricated using e-beam and focused ion beam for electrochemical sensors
  - Determine the effect of electrode material on the **selectivity and detection limit**
  - Determine the spatial limits in **simultaneous multi-analyte electrochemical sensing**
- Teaming
  - Dr. Erno Lindner (PI), UT/U Mem Joint Program in Biomedical Engineering, will be responsible for sensor design, modeling and characterization

Electrochemical Sensor Background

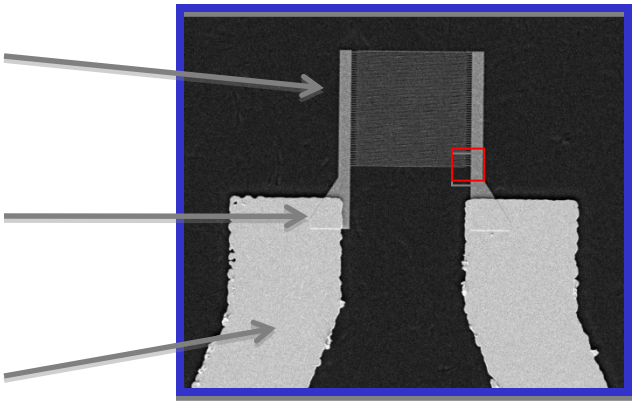
- Microelectrode Arrays (MEA)
  - Wells fabricated in polyimide over Au disk
  - Current measurement is less demanding
- Interdigitated Microelectrode Arrays (ID-MEA)
  - Offers significant signal amplification (redox cycling)
  - Sensitivity increases as the electrode thickness increases and the gap between the electrodes decreases
- Nanoscale Improves Electrochemical behavior
  - Electrochemical sensitivity improves as the dimensions of the working electrodes become smaller
  - The improvement is related to the increased mass transport rate

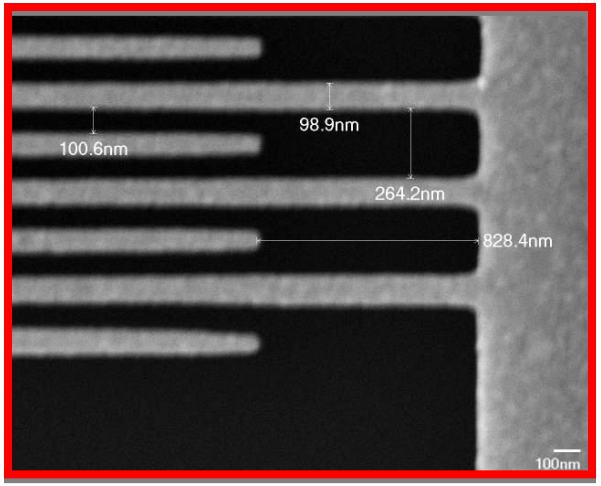


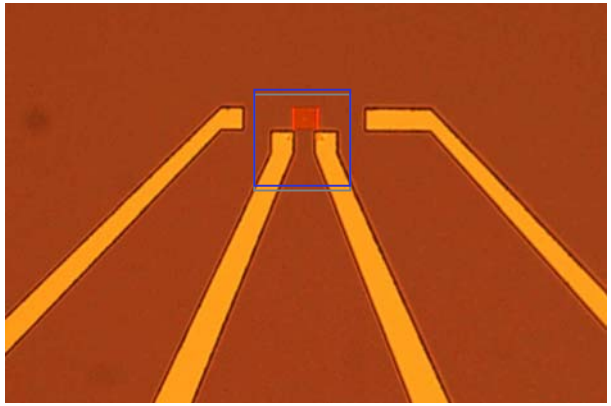
Current MEA/ID-MEA design. Smaller features and materials other than gold are expected to provide unique advantages.

Electrochemical Sensor Fabrication

- Combine e-beam and standard lithography using “landing pads”
- Developed processes for 100 nm electrodes in Au, Pt and ITO
- Overlay PDMS microfluidic channel







Plasmonic Device Applications

- **SP-based photonics are being developed that can drastically reduce the physical size of components over other optical approaches. WHY NOW??**

- **In an SP structure the electromagnetic wave, can propagate along the metal surface in the form of an SP.**

- **The fields can be strongly confined to the metal surface with the lateral dimensions much smaller than the wavelength.**

- **Plasmonic circuits possess both the capacity of photonics and miniaturization of electronics, opening a new way for the future applications.**

Applications include subwavelength photonic components for communications systems such as mirrors, lenses, plasmonic crystals, and waveguides capable of manipulating plasmonic signals.

Current computing systems will also be positively impacted by having similar photonic interconnects to replace current electronic intra-chip and inter-chip interconnects

Active Control of Plasmonic Devices

- **One of the most important yet challenging requirements for applications in photonics, opto-electronics, and optical communications is to introduce a means to control the optical properties of plasmonic devices.**

- **To directly influence surface plasmons and hence the associated optical properties, manipulation of the refractive index of the dielectric medium adjacent to the metal surface is the method of choice.**

- **Choices: Thermal Tuning (thermo-optic coefficient)**

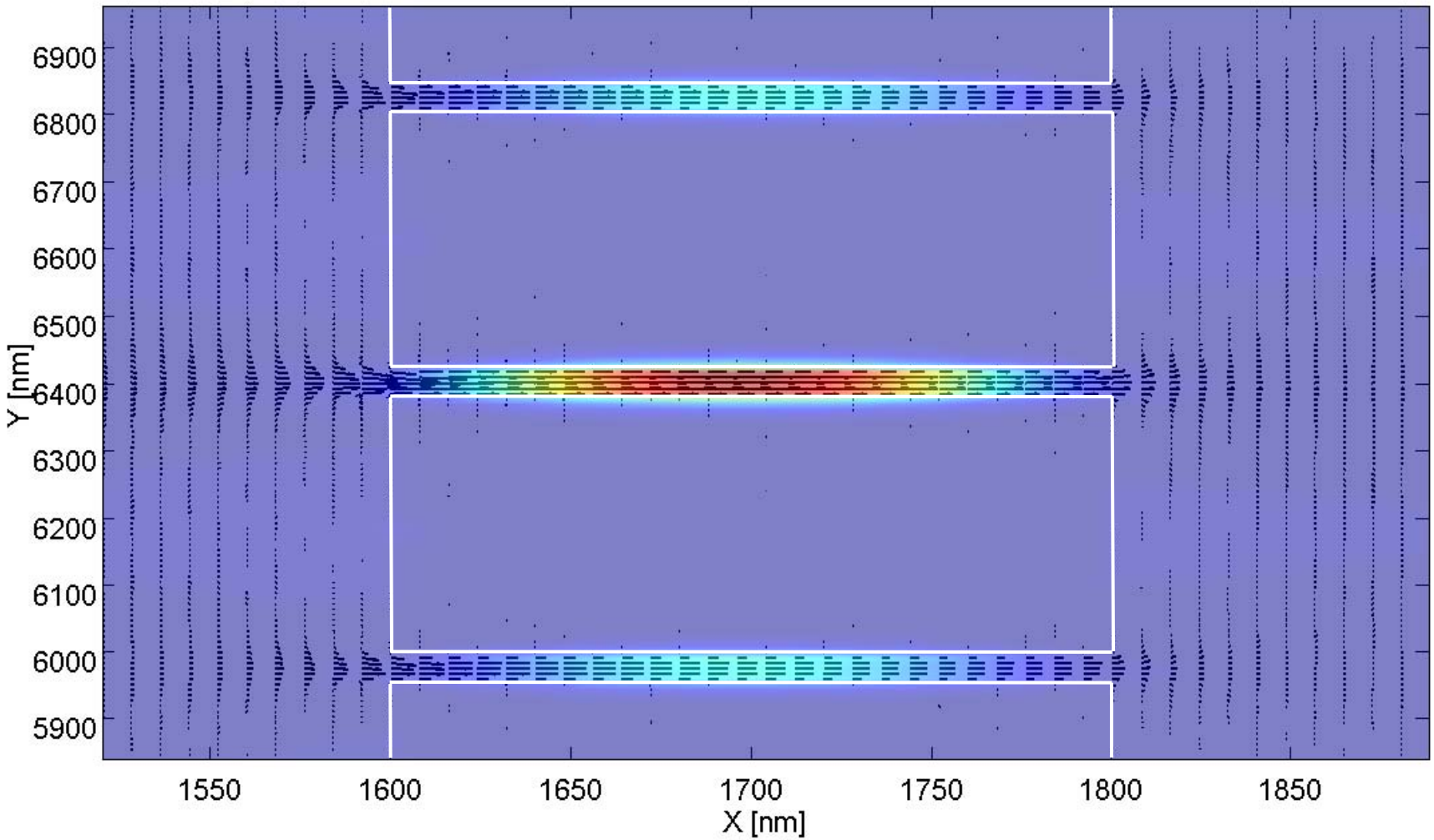
  Free-carrier Injection

  Active Optical Materials (electronic control)

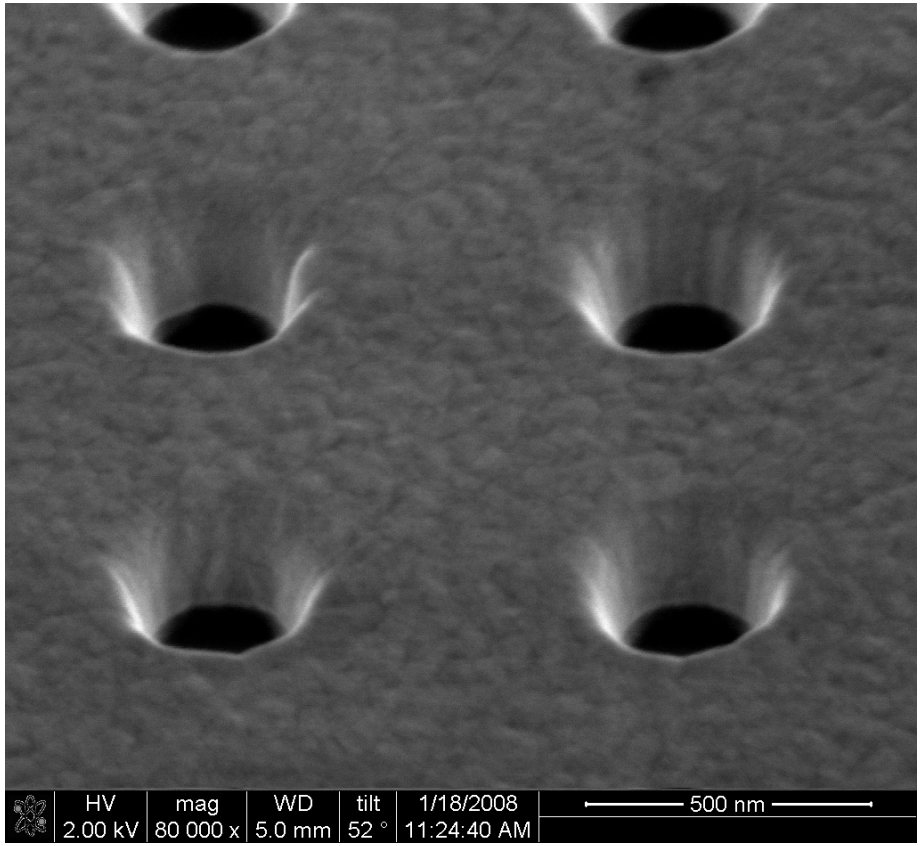
- **For the active optical approach there are two choices: liquid crystals and electro optic polymers**

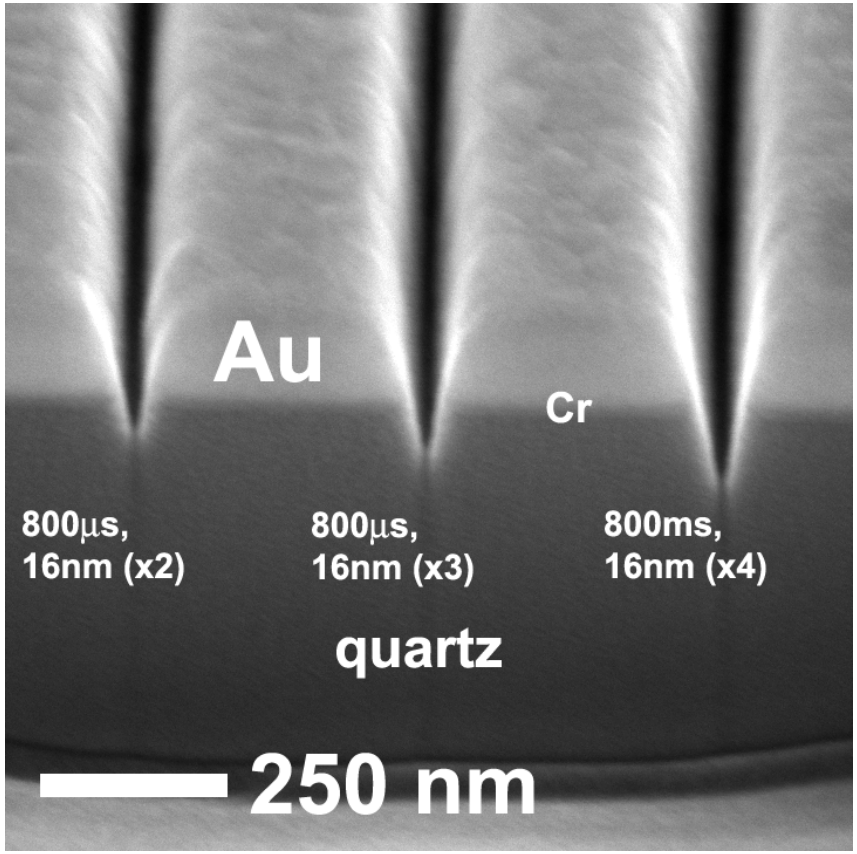
32nm slit 424nm apart 200nm Silver substrate

T=696%



Analysis of Hole and Slit Taper





New CNMS User Proposals

"Enhancement of nonlinear frequency conversion and other nonlinear optical processes in plasmonic structures."

"Development of novel tunable metamaterials and metamaterial-based devices for the visible waveband."

"Plasmonically coupled photonic crystal slab waveguide for NIR wavelengths."

Great Stuff About the CNMS Process

- Superb Scientific Staff, excellent and enthusiastic cooperation, hard working, parallel scientific interests
- State-of-the-art facility for nanotechnology research
- Very good coordination and scheduling of facilities
- Good training process
- Convenient to Huntsville (220 miles via interstate)
- Two proposal calls per year
- Reasonably short proposal and review process
- Relatively easy access WRT badges and building.

Improving Facility Exposure

- An increase in business/industry activity requires a champion who spends a significant percentage of time (30-50%) as a user facility-industry outreach liaison. ORNL has a full time DoD-DoE liaison.

- Make sure people know you exist through proactive outreach
  1. Advertize on Fed Biz Opps: https://www.fbo.gov/
  2. Every DoD Organization has an Office of Small and Disadvantaged Business Utilization (SADBU)

  http://permanent.access.gpo.gov/lps57820/www.acq.osd.mil/sadbu/index.htm
  http://www.donhq.navy.mil/OSBP/
  http://www.selltoairforce.org/
  http://www.sellingtoarmy.info/user/showpage.aspx?SectionID=9#

  Every SADBU office has a person who is supposed to seek out opportunities for small business to work with other organizations on DoD related research and development
- Make certain that your tech transfer office is aware of your capabilities.

Access and Proposal Process

- There are several access mechanisms to the Facility:
  - Open proposal
  - Fast Access proposal
  - CRADA
  - Proprietary User Agreement

  All take time and the Proprietary User Agreement is still not available.

- Add Business/Industry Participants to the Review Committee (CNMS numbers)
  - Academic Reviewers 65
  - Industry Reviewers 2
  - FFRDC Reviewers 4

Project Execution

When Industry and User facilities work together they have different objectives (Publications and awards vs. patents and product development)

When possible assign a staff member with similar research interests to work as a team with the user

- Kickoff/planning meeting
- Regular reporting and communication
- End products planned from Day 1
- Final report and collection of IP and pubs

Select projects that can be sustained through other funding sources. Staff and user collaborative proposals

Project Execution

During project execution industry must provide travel and salary for users.

One opportunity for funding small business is through SBIR proposals. User facilities should work to ensure that facility related research topics are included in the DOE SBIR solicitations

DoD administers a well-run successful SBIR program with very clear SBIR solicitations. They have 3-4 proposal calls per year with several hundred solicitations per year. See examples at:

http://www.acq.osd.mil/osbp/sbir

Several states provide SBIR matching money

Project Wrapup

When a project is finished a detailed final report should be required because:

A facility needs the publication, patent, award information for performance metrics.

A facility can't market success stories without documenting them.

These success stories can be marketed to other businesses, the public, funding agencies, etc.