# NOVEL PLASMONIC DEVICES FOR NANOPHOTONIC NETWORKS: EXPLOITING X-RAY WAVELENGTHS AT OPTICAL FREQUENCIES

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**Objective**: Plasmonics enable *truly* nanophotonic components for communications, imaging and spectroscopy by exploiting localized and propagating surface plasmons that access *nanometer-scale wavelengths at optical frequencies.*

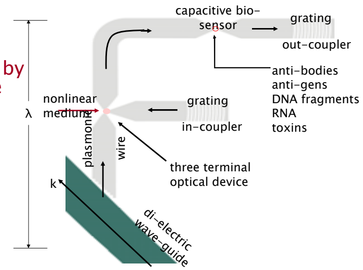
**Impact**: This MURI is creating

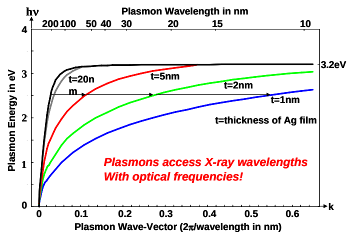
(a) new plasmonic material designs

(b) comprehensive design and experimental realization of subwavelength component active and passive devices and small, circuit-like networks

(c) a toolbox of design methodologies for plasmonic networks and circuits.

**Relevance**: Deliverables will enable ultracompact, robust and highly efficient photonic components and networks for communications, imaging, and detection optimally suited for insertion into mobile military platforms.

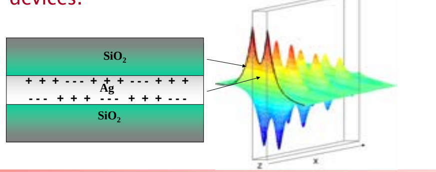


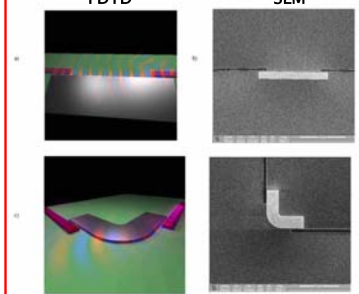

## Plasmonics is Opening a New Domain for Integrated Photonics

based on:

- Extreme light localization: nonlinear excitations in ultrasmall volumes → compact low-power all-optical devices
- Very high spatial frequencies: opportunity for optical imaging systems with nm-scale resolution
- Enhanced light-emission from active photonic devices via coupling to surface plasmons
- Coupling from dielectric (fiber and SOI waveguide-based) photonics to plasmonic devices.




## Coupling to/from Dielectric and Plasmon Waveguides

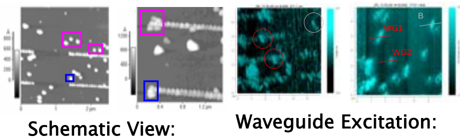



1550nm surface plasmon mode, coupled to and from SOI waveguide:

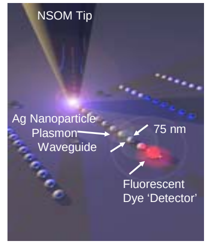
- No diffraction limit to modal volume
- ~1.2 dB/μm loss achieved (limited by roughness of silver film)
- ~2.8 dB insertion loss from SOI to plasmon waveguide

## Ultra-Small (~λ/10) Plasmon Waveguides Below Diffraction Limit

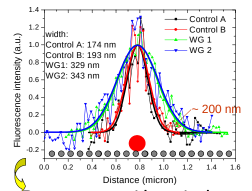
Force manipulation positioning of detectors: Topography: Fluorescence:



Schematic View:



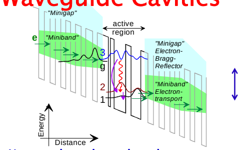

Waveguide Excitation:

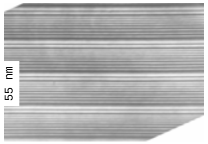



Dyes on waveguide excited over a waveguide distance ~1 μm

*Maier, et. al. Nature Materials, April 2003*

## Quantum Cascade Lasers with Plasmon Waveguide Cavities

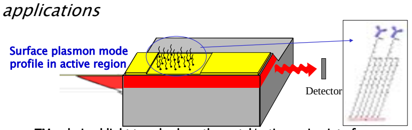



AlInAs/GaInAs

Unprecedented wavelength coverage (mid-ir, lw-ir, far-ir) by changing active region thickness: from 3 μm to 150 μm !!

Laser polarization is *normal to layers* (TM mode): has *enabled first surface plasmon laser*, and allows innovative *plasmonic resonator designs* suited *for chem/bio sensing applications*

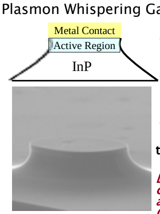



TM polarized light travels along the metal/active region interface

Surface plasmon field used to sense analytes adsorbed on top metal contact by monitoring changes in laser characteristics (threshold, power, λ).

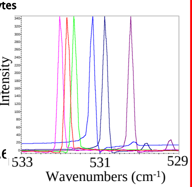
Self-assembled monolayers (SAM) deposited on thin Au contact can be functionalized with capture agents for specific analytes

Plasmon Whispering Gallery Mode Lasers




- Stripes: $J_{th}$=3.2 kA/cm²
- Circular disks (r=40 μm): has $J_{th}$=1.5 kA/cm²
- Deformed microdisks (ε from 0 to 0.3): $J_{th}$ from 1.6 to 1.8 kA/ cm²

*Decrease in threshold compared with stripe laser at same λ due to increase in Q*

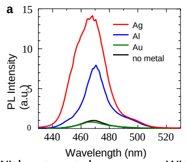


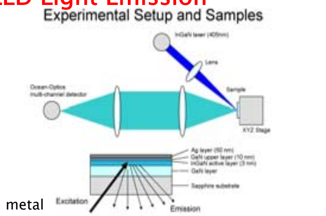

Spectral tuning of nearly circular (ε =0.027) laser for increasing current.

ε = ratio of minor to major axis

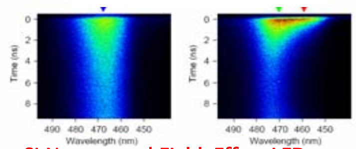
## Plasmon-Enhanced LED Light Emission

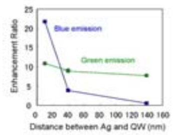
InGaN Quantum Wells:




Without metal    With metal

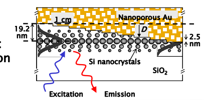


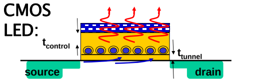

## Si Nanocrystal Field-Effect LED:

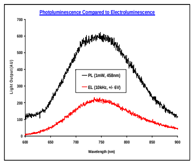
- New light emission phenomenon in Si MOS transistor
- Sequential field effect carrier injection into Si quantum dots: program electrons in inversion, program holes in accumulation
- Device fabbed in state-of-the-art Intel CMOS foundry

Plasmon-Enhanced Emission:

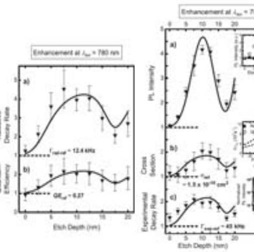



CMOS LED:

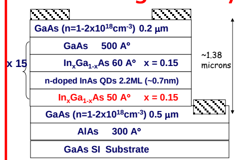







## Plasmon-Enhanced Detection in Long Wave-Length IR Hyperspectral Arrays

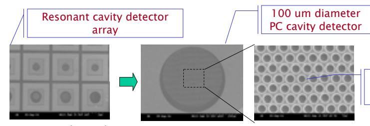



LWIR Atmospheric Window DWELL Design

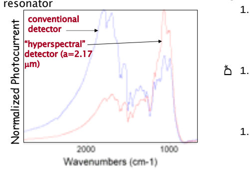
Mid-infrared photodetectors in 50-400 meV (3-25 μm) range:

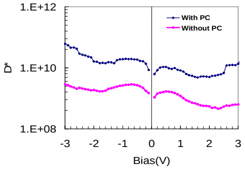
- medical diagnostics,
- thermal imaging,
- night vision for battlefield recognition systems
- chip-based detection of chemical warfare agents

Intersubband quantum dot detectors: promising technology → normal incidence excitation and lower dark currents. InAs quantum dots in an InGaAs well (DWELL) for mid-IR detection (Krishna at UNM)… *but presently suffer from low quantum efficiency and responsivity due to small absorption volume.*




- Resonant enhanced detection using in-plane resonator
- Metal contact serves dual purpose of optical waveguiding (mode-matching) and electrical read-out

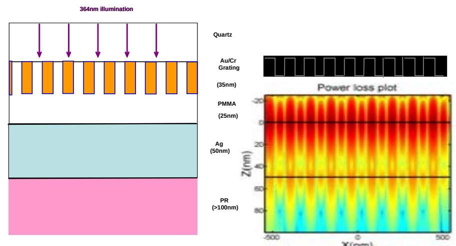


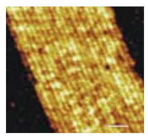

- Spectral response of an enhanced "hyperpectral" versus a conventional detector. (spectra normalized to peak detected wavelength to compare wavelength sensitivity)
- Enhanced detection efficiency for longer (9 μm) wavelengths; shorter wavelength (6 μm) suppressed
- The generation-recombination limited D* at 77K a factor of 20 higher than that of the conventional detector
- BLIP temperature raised by 20%

## Superlenses: Imaging Below the Diffraction Limit

Design    Simulated Intensity




Array of 60 nm wires    Arbitrary object "NANO" (100 nm lines)



1. At grating, propagating field converts to an evanescent wave
2. At the silver surface, the evanescent waves experiences weak scattering from surface, but major component maintain the original grating wavevector;
3. Exiting from silver surface, evanescent field components recombine to form near field images