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Plasmonic-electronic transduction

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### Abstract
Plasmonic-electronic integrated circuits have been suggested, but input and output continue to rely on bulky free space optics and inefficient couplers such as prisms. The objective of this project was to study direct electronic generation and detection of plasmons. Since plasmonic-electronic interactions are known in the long-wave IR and THz frequency domains, but not in the optical range usual for plasmonic applications, it was necessary to first develop plasmonic materials and devices for the longer wavelengths. Then, interactions between plasmons and electronics were studied with the long range goal of developing electronic-plasmonic transducers. The work was strongly leveraged by collaborative interactions between the PI, his students, and the AFRL at Hanscom AFB. Research accomplishments are well described in publications that acknowledge this award, including 7 refereed journal papers, 29 conference publications, 3 dissertations and thesis, and one book chapter. The specific accomplishments and topics studied include tunable THz detectors based on plasmon resonances in two dimensional electron gases, new materials for infrared plasmonics, cathodoluminescence study of plasmons on metal gratings, and plasmonic properties of Gold Black nanoparticles.
Reason for work
Plasmonic-electronic integrated circuits have been suggested, but input and output continue to rely on bulky free space optics and inefficient couplers such as prisms. The objective of this project was to study direct electronic generation and detection of plasmons. Since plasmonic-electronic interactions are known in the long-wave IR and THz frequency domains, but not in the optical range usual for plasmonic applications, it was necessary to first develop plasmonic materials and devices for the longer wavelengths. Then, interactions between plasmons and electronics were studied with the long range goal of developing electronic-plasmonic transducers. The work was strongly leveraged by strong collaborative interactions between the PI, his students, and the AFRL at Hanscom AFB.

Summary of work done
Research accomplishments are well described in publications that acknowledge this award. These include 7 refereed journal papers, 29 conference publications, 3 dissertations and thesis, and one book chapter. The work done may be summarized as follows.

Tunable THz detectors based on plasmon resonances in two dimensional electron gases.
Tunable plasmon absorption resonances were observed and studied in InP-based and GaN-based HEMTs. The former were manufactured at AFRL Hanscom. The latter were studied at UCF in collaboration with RPI. Initial observations of plasmons in large area CVD graphene devices fabricated at UCF were also observed. Work continues in collaboration with AFRL WPAFB on the transduction of the plasmon absorption to a useful electronic signal.

Materials for infrared plasmonics
To achieve the subwavelength confinement of electromagnetic surfaces waves known at visible wavelengths on noble metal surfaces requires new materials with IR plasma frequencies. A number of materials were investigated, including metal silicides (Pt-, Pd-, Ni-, W-silicides), semimetals (Sb, Bi, graphite), doped-semiconductors (Si, CuInSe), and conducting polymers (polyaniline and polyaniline-graphite mixtures). These were evaluated theoretically and experimentally for their potential in IR plasmonic waveguides and IR surface plasmon resonance biosensors.

Cathodoluminescence study of metal gratings
The purpose of this study was to investigate electron beam excitation of surface plasmons, and their propagation, at nano-meter length scales. Micromachined grating structures fabricated in various materials at AFRL Hanscom were used to out-couple e-beam excited surface plasmons to a spectrometer for analysis. A number of systematic but puzzling effects were observed. Explanation of these effects has been constrained by numerous experiments with different materials, grating periods, grating amplitudes, grating orientation, grating size, e-beam energy, and e-beam current, and e-beam positioning. These clear and repeatable effects are not in agreement with the results and interpretations of similar experiments performed by other groups. A complete understanding, including the role of surface plasmons, for the observations is still under development, guided by additional constraining experiments and theory.

Plasmonic properties of Gold Black
Gold black consists of nano-structured filaments of gold which has been used for decades as an ultrabrack broad-band coating for IR bolometers. We investigated the potential of sparse gold-black coatings as plasmonic scattering centers for enhancement of thin-film solar cell efficiency. Significant improvements were observed experimentally. Additionally, the plasmon resonance...
excitation spectrum and spatial distribution was investigated via Photoemission Electron Microscopy during two visits to the Environmental Molecular Sciences Lab in Richland WA.

Participants
Nearly all of the work was performed in close collaboration with AFRL Hanscom AFB, particularly fabrication and simulations efforts. Since the closing of this facility in 2011, the entire wafer fab and many characterization tools was transferred to a new cleanroom facility at UCF, who paid for the move and installation fees. This unanticipated windfall and opportunity for continuity in fabrication required significant efforts that were supported by the grant during its last few months. The supported students provided the labor for the move and installation, so that the project could continue. One of the project participants, Justin Cleary, received his PhD and took a position at AFRL Hanscom. He has since moved with Walter Buchwald’s THz lab to AFRL WPAFB, where he continues to collaborate with us. Indeed, one of the PIs current students Nima Nader is spending a year working with Dr. Cleary in Dayton.


AFRL Hanscom: Senior personnel: Dr. Walter Buchwald, Dr. Richard Soref, Dr. Justin Cleary

Other: A number of other researchers contributed to the published research without direct or in-kind support from this award. See publication list for their names.

Journal publications resulting from this project.

Conference publications


PhD Dissertations and MS Thesis
1. Himanshu Saxena, “Tunable terahertz detectors based on plasmon excitation in two dimensional electron gases in InGaAs/InP and AlGaN/GaN HEMT, (2009), Subsequent Employer: Zyberwear Inc. Orlando FL

Book Chapter