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OPTICAL SENSING AND IMAGING OPPORTUNITIES

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14. ABSTRACT
There were several component actions under this award.The first component involved critical analysis of ongoing AFOSR supported research programs related to complex oxide thin film deposition, characterization and potential device applications.The second component was to identify new areas in which AFOSR could fund in support of Air Force programs.The third task was to assist in formulating MURI and BRI topics and formulation of CFPsThe final task was to report advances presented at the annual International Multi-Functional Materials Workshops, supported by AFOSR.Potentially Useful New Research Areas.- Plasmonics- Infrared antennae- IV-VI (lead salt) Infrared Photo Detectors and Focal Plane Arrays- Hexagonal Ferrite Thin Films for Q-Band Signal Processing DevicesMultifunctional Materials WorkshopsThe three annual multi-functional materials workshops (MFM-6, 7 and 8) supported by AFOSR during the period of this award were attended and reports submitted independently.

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Final report for Commercial Grant #FA9550-10-1-0506 entitled: Optical Sensing and Imaging Opportunities.

There were several component actions under this award.

The first component involved critical analysis of ongoing AFOSR supported research programs related to complex oxide thin film deposition, characterization and potential device applications.

The second component was to identify new areas in which AFOSR could fund in support of Air Force programs.

The third task was to assist in formulating MURI and BRI topics and formulation of CFPs

The final task was to report advances presented at the annual International Multi-Functional Materials Workshops, supported by AFOSR.

Mentoring OSR Supported Research Programs

This involved site visits with AFOSR supported principle investigators at Virginia Commonwealth University, ferro-electitric, magnetic and multi-ferroic materials thin film deposition, characterization and potential device application. Lead-free piezo-electrics at Virginia Tech., quantum dot technologies at the University of Southern California and novel techniques for overcoming lattice mismatch at superlattice heterojunctions between materials used for optical sensors, with Dr. Gail Brown of WPAFB.

This component involved feedback to and mentoring of the PIs and providing novel concept and technique input for increase productivity and technically creative technology advances.

Potentially Useful New Research Areas.

- **Plasmonics**
- **Infrared antennae**
- **IV-VI (lead salt) Infrared Photo Detectors and Focal Plane Arrays**
- **Hexagonal Ferrite Thin Films for Q-Band Signal Processing Devices**

Plasmonics

New techniques for transmitting optical signals through nano-scale structures. For example, directing light waves at interfaces between a metal and a dielectric can induce resonant interactions between incident waves and mobile electrons at the metal surface. I.e. oscillations of electrons at the surface match those of the electromagnetic field outside the metal. The result is the generation of surface density waves of electrons that propagate along the interface.

It is possible to generate surface plasmons with the same frequency as the incident light but with a much shorter wavelength.

This phenomenon would allow plasmons to travel along nano-scale interconnects, carrying information from one part of a detector devices to another.

Optical on-chip interconnects

Plasmonic interconnects will also enable chip designers build electronic circuits that can move data quickly across chips.

Chemical and Biological Sensors

Ultimately plasmonic components can be employed in instruments by improving resolution of microscopes, LED efficiency and sensitivity of chemical and biological material detectors etc.

Cloaking

Plasmonic materials may possibly change electromagnetic fields around an object to make it essentially invisible.

Infrared antennas

Infrared analogues of microwave antennae are not yet practical in real applications.

Metals might not be the right choice of material for antenna elements with diameters < 5 nm, as conductivity becomes too low. Carbon nanotubes are better conductors than metals at diameters <5 nm. Graphene and nanotubes are therefore suggested as the best choice for Infrared antennas.

Nonlinear Infrared antennas can be used for frequency-selective local interactions across the entire visible and infrared spectrum.

It is not yet clear how to compensate for large impedance mismatches between Infrared antennas and radiation fields.

Infrared antennas are potentially a technology for manipulating light at the nanometre scale and providing optimal control of far-field transduction. Although antenna configurations can now be realized at Infrared frequencies, impedance matching needs redefining for IR detectors. Infrared antennas connect to quantum systems involve new physics such as selection rule breaking. Once fabrication techniques have been improved, many applications are possible, including light harvesting, energy conversion, nanoscale Infrared circuitry and Infrared imaging beyond 10 nm resolution.

IV-VI (lead salt) Infrared Photo Detectors and Focal Plane Arrays

This component addresses the potential of lead chalcogenides (IV-VI or lead salt) alloys for more readily manufacturable high performance optical detectors and very large area focal plane arrays in the visible through >24 micron wavelengths.

The ultimate sensitivities obtainable with IV–VI compounds are similar to those of II–VI narrow bandgap semiconductors such as $Cd_{1-x}Hg_xTe$ (MCT) under similar conditions (i.e., bandgap and operating temperature). IV-VI alloys, on the other hand, span the same wavelength ranges from visible to far IR and have high carrier mobilities and minority carrier diffusion lengths. In addition they are easier to grow by MBE, MOCVD etc.with good composition and doping control and are much more stable materials than mercury based IR detector films.

Hexagonal Ferrites for Q-Band Signal Processing Devices

Hexagonal ferrites such as barium and strontium hexaferrites $BaFe_{12}O_{19}$, $SrFe_{12}O_{19}$ and their alloys such as SrLaxFe12-xO19 and $BaFe_{11.1}Sc_{0.9}O_{19}$ have high internal magneto-crystalline anisotropies, with natural resonances in the 30–70 GHz range and are self magnetically biasing eliminating the costly permanent magnets. Ultra-small microstrip and coplanar waveguides using such thin films virtually eliminate the need for thick hexagonal ferrite films or external magnets. **G**rowth processes need to be correlated with hexagonal ferrite thin film microstructure properties, and physical relaxation with small damping, close to that of single-crystal; exploration of new hexagonal ferrite thin films and engineering nano-magneto-crystalline anisotropy; modification of hexagonal ferrite nano-structures to continuously tune ferromagnetic resonance frequency.

The aim is to develop full understanding of a broad class of low loss, tunable, reliable, and affordable Q-band signal processing devices, monolithically integrated with microwave circuit technology.

Success will allow a range of novel low cost high performance tunable microwave electronic circuits operating in the Q-band frequency range without the need for heavy permanent biasing magnets.

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Basic Research Initiative (BRI) topic suggestion (2012)

Basic Phyllo-crystalline Hetero-structure Science

The aim of this BRI topic is to discover, model and understand the properties of new and novel artificial 2-dimensional (phyllo-) lattice insulators and magnetic materials, and their heterojunctions with established 2 dimensional materials including graphene, BN and metal di-chalcogenides, with potential application in high frequency devices.

The objectives of the proposed effort are:

(1) develop a basic scientific understanding of bi-, tri- and multi-layer heterostructures of 2D semiconductor/ insulator, semiconductor / magnetic phyllo-crystal, magnetic phyllo-crystal / phyllo-insulators, triple and multi- layer structures including all three types of phyllo-materials. Phyllo-super lattice structures are also of strong interest.

(2) Develop methods for their epitaxial preparation,

(3) determine interfacial, electrical, physical, optical and chemical properties

(4) develop predictive models for hetero-phyllo-interfacial crystallography

(5) demonstrate and model how these types of phyllo- heterostructures could be used for novel and increased functionality in high frequency (and other potentially useful) applications.

(6) explore the beneficial effects of dopants and ligand (C-l, CH3- etc.) substituted / derivative phyllo-heterostructures for potential application in high frequency (and other potentially useful) devices.

The above goals involve systematic study and basic scientific understanding of the properties of magnetic / insulator / semiconductor phyllo-structure interfaces and first principles (opto-) electronic- modeling.

There has been much recent interest in graphene and other two dimensional semiconductor materials BN and MoS_2. The SP2 hybridized electron orbital arrangement of graphene allows the extra electron in each carbon p_z orbital to delocalize, forming two dimensional electron gases above and below the hexagonally bonded carbon atom sheets.

Similarly the two electrons from each p_z orbital of nitrogen in hexagonal boron nitride delocalize into the empty boron p_z orbitals with a similar 2D gas effect. The molybdenum di-chalcogenides are also being intensively studies for electron gas device applications.

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Multifunctional Materials Workshops

The three annual multi-functional materials workshops (MFM-6, 7 and 8) supported by AFOSR during the period of this award were attended and reports submitted independently.

These workshops were each attended by ~40 top research scientists and have led to several international collaborative efforts which multiply individual research effort productivity..

In summary four components of this award have identified novel areas of research of great potentially use to AFOSR technology. Mentoring and collaborative help was provided to several principle investigators funded by AFOSR, A basic Research Initiative topic was formulated, and three multifunctional workshops funded by AFOSR were audited and reports of important materials and applications reported.

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