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Building upon this foundation Professors Barry Gross, Fred Moshary and Sam Ahmed of City College's Department of Electrical Engineering are investigating a number of promising research and development projects for Homeland Security applications. In the event of the release of chemical or biological agents in urban areas it would be vital for the first-responders to know how the agent is spreading. A wind lidar scanning the skyline above the rooftops can map real-time wind velocities that can be fed into a forecasting model that, in turn, provides real-time dispersion forecasts to a command and control center. City College, which is located on a hilltop with a commanding view of the downtown Manhattan area, is well suited for pilot implementation of such a system.

Release of agents into the atmosphere is often in the form of aerosols. In an open field, such as a battlefield, aerosols can be located and traced via a scanning eye-safe method such as infrared lidar in real time, with wavelengths that do not damage the retina, thus allowing personnel to avoid areas of high aerosol concentration.

Short-range tunable laser diode based CW-FM Lidar-Improved instrumentation can be utilized in urban areas to detect possible air toxins and track their movement in urban environments. For this application small, relatively inexpensive, low-power remote detection instruments are possible. Such systems can work as an agent-specific remote sensing system, with the transmitter tuned to the absorption line of a specific chemical or biological agent.

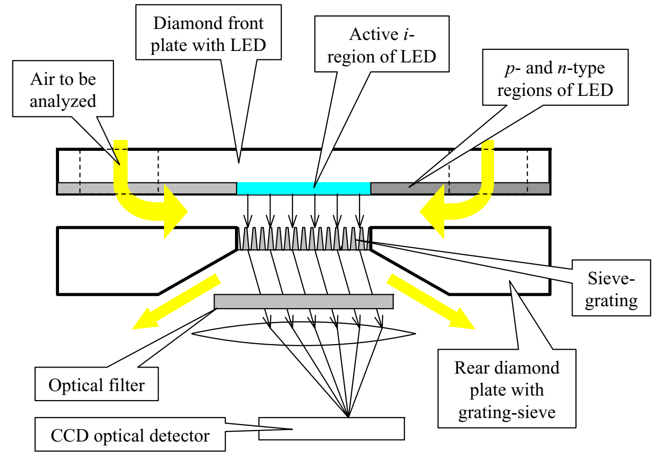
Open-Path Fourier Transform Infrared (FTIR) Spectroscopy is a powerful laboratory technique for chemical analysis of samples. It enables continuous simultaneous detection of a host of chemicals (organic and inorganic) using high-resolution infrared absorption spectra over a very broad band. Field application of this technique is possible using an open-path system where an infrared source is placed up to 2 km from the FTIR receiver. This eye-safe technique can be deployed in a variety of conditions and requires only a clear line of sight.

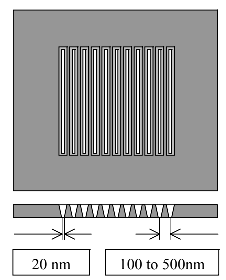
Utilizing Smart Optical Diamond Window Filters

The use of a diamond window capable of detecting large chemical and biological molecules by means of optical absorption, photoluminescence, or Raman scattering is under investigation by Professors A.M. Zaitsev and A.A. Gorokhovsky of the College of Staten Island.

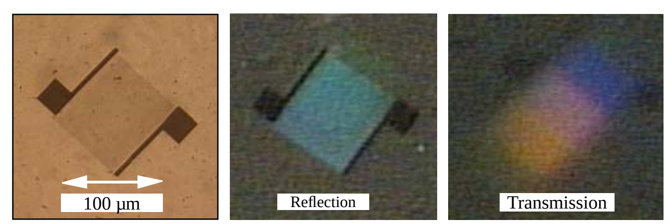
The main part of the "window" consists of a nano-grating made on a few micrometer thick diamond membrane. The grating serves as a molecular "sieve," trapping from the air large molecules and bacteria and accumulating them. Laser excitation of the grating provides luminescence from the absorbed molecules without background emission from the filter, which can then be identified via spectroscopic methods.

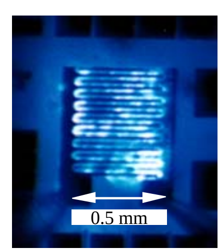
Diamonds possess strong resistance to radiation, a broad working temperature range and high chemical and mechanical stability. Those qualities make diamond-based detecting devices highly reliable and well suited for battlefield conditions, according to Professors Zaitsev and Gorokhovsky.





Above: Scheme of the "smart diamond window". The light of LED located in the front diamond plate passes through transparent sieve-grating located in the rear diamond plate. The hollow slits of the grating serve as a percolation sieve letting through the air molecules but trapping large organic molecules and bacteria. Luminescence or absorption caused by the trapped molecules are characterized spectroscopically. Left: Sieve-grating on diamond membrane. The membrane thickness may range from 0.5 to a few micrometers. Such a grating can be made by fine focus ion beam technique.





Above: Diamond micro-grating made by fine focus ion beam technique.

Left: Planar interdigital diamond p-i-n LED emitting blue light.

ADDITIONAL SUPPORT IS REQUIRED

The CUNY-CAT is seeking additional funding to expand its research in detecting biological, chemical and radioactive agents.

"A rapid detection and response capability is vitally important in the event of terrorist attacks utilizing these deadly agents," said Professor Robert R. Alfano. "We are making enormous progress in that direction and I am confident that photonics technology is destined to play an increasingly significant role in this effort," he added.

For further information, please contact Dr. Robert R. Alfano, Director; Mr. Alan Doctor, Manager of Business Development, CUNY-CAT; or Ms. Masada Disenhouse, Deputy Director, CUNY-CAT. Telephone: 212-650-8261. E-mail: masada@ee.ccny.cuny.edu

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The IUSL Report

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Special Edition

This paper offers an overview of promising research advances in photonics at The City College and The City University of New York to develop new tools for defending the nation against terrorism involving biological, chemical and radioactive agents. These advances are based on research by scientists at the New York State Center for Advanced Technology in Ultrafast Photonics at CUNY, and at City College's Institute for Ultrafast Spectroscopy and Lasers.

Since the attacks of 9/11, terrorism has been a major preoccupation of federal, state and local authorities. Terrorism can take many forms, from suicide bombs, to car and truck bombs to aircraft high-jacking, as well as the use of biological, chemical and radioactive agents.

Among the most deadly forms of terrorism are those utilizing biological and nuclear agents, including agents that can be disseminated through the mails. For residents of large cities who live, work and travel in densely crowded areas, biological, chemical and nuclear terrorism is especially frightening.

CUNY's Photonics Technology is Developing New Tools to Combat Terrorism

BACKGROUND: CUNY's Photonics Initiative

Photonics involves the use of small units of light called photons. Photons have unique properties: they travel at ultrafast speed, have color, can be directed easily and emit short pulses on the order of the molecular timescale measured in picoseconds (trillionths of a second = 10^{-12}) to femtoseconds (quintillionths of a second = 10^{-15}).

Over the past two decades, scientists at City College's Institute for Ultrafast Spectroscopy and Lasers (IUSL) have pioneered in research utilizing light and photonics technology in studying biomedical systems; developing tunable solid state lasers, picosecond lasers and femtosecond lasers; investigating time resolved techniques and their application to a broad range of studies in biomedical optics as well as primary events in photosynthesis, vision and tissue diagnosis; and studying fundamental energy transfer processes in liquids, semiconductors and solids.

In 2000, The City University, already a major force in the photonics field by virtue of its research accomplishments and faculty base at the IUSL, established a flagship Photonics Initiative. Dr. Louise Mirrer, Executive Vice Chancellor for Academic Affairs at CUNY, is highly supportive of the Photonics Initiative. The objective is to bring photonics technology at the various CUNY colleges under a single umbrella in order to focus and enhance the University's efforts. The Photonics Initiative is aimed at elevating CUNY to the highest ranks of university photonics research internationally through the development of new facilities, expansion of educational opportunities in photonics and "cluster hiring" of new faculty.

The logistics for the Photonics Initiative are directed by Dr. Gillian Small, CUNY's Acting Dean of Science.

According to CUNY Chancellor Matthew Goldstein, cluster hiring involves bringing to the University significant sized cohorts of new faculty in selected programmatic areas. Cluster areas are chosen for their importance to society and the economy, their relation to existing CUNY strengths, their relevance to educational need and their intellectual breadth and depth. Each area is allocated a multi-year package of resources, including a cluster of faculty and staff positions and an appropriate level of start-up funds.

The Photonics Initiative focuses on biophotonics, biosensing, biomedical optics, semiconductor quantum dots and wells for emitters and detectors, photonic band gap structures, nanoscale particles for light sensors and displays, organic polymers for displays and fast switches, tunable lasers, and ultrafast laser technology.

In just the past three years there have been eight new faculty hires in photonics and six searches are in progress. Fifteen to twenty faculty lines and staff positions will be allocated in all, including several associated with the New York State Center for Advanced Technology in Ultrafast Photonics at CUNY, which is headquartered at CCNY, the University's lead campus for photonics. In addition, several new photonics faculty have been hired on college lines.

New York State's Center for Advanced Technology in Ultrafast Photonics at CUNY

Established in 1993, The New York State Center for Advanced Technology in Ultrafast Photonics at CUNY (CUNY-CAT) promotes economic development

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in New York State by generating and disseminating knowledge in photonics technology. The Center is supported by the New York State Office of Science, Technology and Academic Research (NYSTAR); industry partners; and The City University. The CUNY-CAT is headquartered at City College and directed by Dr. Robert R. Alfano, Distinguished Professor of Science and Engineering at CCNY. Facilities and equipment are available on the campuses of five CUNY senior colleges. Approximately 20 faculty members from the University's science and engineering departments are affiliated with CUNY-CAT.

Based on pioneering work in photonics conducted at City College over the past 20 years, CUNY has unparalleled research and development capabilities in non-invasive medical diagnostic techniques (e.g., breast and prostate cancer detection), tunable laser development, optical imaging, novel semiconductor materials and structures, and nanoscale photonic materials. Applications include broad-bandwidth communications, environmental monitoring and biomedical and industrial devices.

In order to assist New York State companies the CUNY-CAT conducts high-level research in its resident technological areas. It has worked closely with over 50 companies in the State since its inception. The CUNY-CAT facilitates commercialization of applications through product development, licensing of intellectual property and technology transfer; provides companies with access to CUNY staff and facilities; trains workers for industry; prepares students for academic and industry careers; nurtures small and start-up companies; and leverages its funding to secure additional resources to further its objectives.

Together with CCNY's Institute for Ultrafast Spectroscopy and Lasers (IUSL), which is also headed by Dr. Alfano, the CUNY-CAT has obtained leveraged funding via over 50 grants totaling in excess of $18 million to support existing capabilities and develop new research areas. Over 250 papers have been published and more 50 U.S. patents have been awarded.

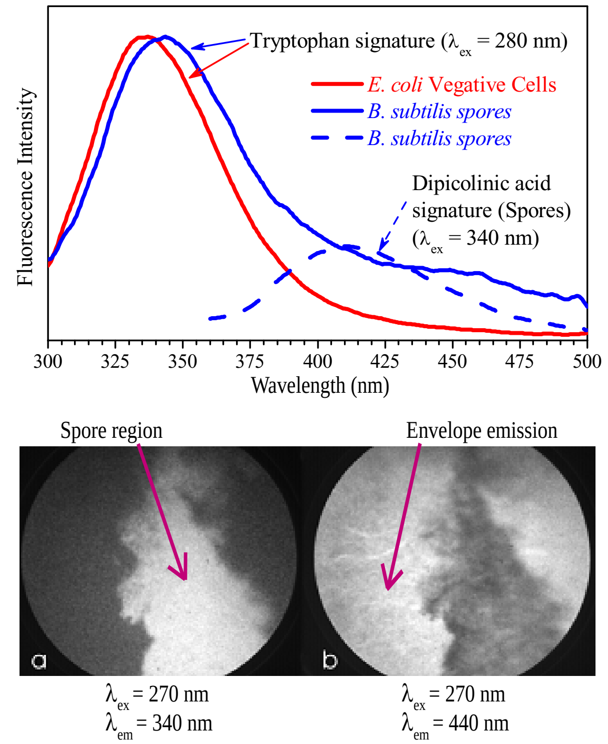
Among the CUNY-CAT's newest areas of concentration are detection of biological, chemical and radiation hazards for homeland security and industry applications; and the development of nanoscale materials for military, and biomedical applications and quantum computing.

Utilizing Photonics Technology for Bio-Defense and Detecting Chemical and Radioactive Agents

BIODEFENSE

The unique properties of light, such as spectral, temporal coherence and polarization, as well as the key photo physical and chemical characteristic properties of the bio-agents, offer the potential to uniquely identify bio-agents, whether alive or dead. Researchers from the Photonics Initiative of CUNY-CAT and the IUSL have joined together to conduct groundbreaking research in the use of time-resolved and steady-state spectroscopy to characterize the optical signatures of biological and medical related molecules in cells, tissues, viruses and bacteria.

For the past two decades IUSL scientists have been investigating the optical properties of cells and biomolecules. The recently established National Aeronautics and Space Administration (NASA) Center for Optical Sensing and Imaging (COSI) at City



Top: Emission spectra from B. subtilis *spores and* E. coli *bacterial cells showing tryptophan emission (from all cells) and dipicolinic acid emission (spores). Bottom: Fluorescence image of envelope coated with* B. subtilis *spores. Left image probes tryptophan emission – spores regions are bright. Right image probes emission from paper – spore region is dark.*

College has as one of its charters the investigation of environmental sensing and detection technologies for biological/chemical presence.

Optical Spectroscopic Detection and Imaging of Bio-Agents

To counter the threat of bioterrorism researchers at The City College are working to develop two generations of optical instruments utilizing photonic technology based on native fluorescence that has succeeded in detecting bacterial cells, spores and viruses *in-situ* and in real time, as well as the absorption spectroscopy. The fluorescence technology has previously been used to develop tools for the early detection of cancer. It is based upon identifying the emission spectral "fingerprints" of proteins found in cells, tissue, bacteria, viruses and spores.

Dr. Alvin Katz of the IUSL is the lead researcher for a project entitled "Optical Spectroscopic Detection and Imaging of Bio-Agents and Cancer."

Effective sensors should provide continuous remote monitoring of the environment and be able to rapidly warn of the presence of a threat, according to Dr. Katz. Ideally, sensors should not use reagents or introduce potentially harmful chemicals into the environment.

Technologies based on optical spectroscopy satisfy these requirements for real-time, non-invasive, *in situ* and remote monitoring. There are several native fluorescing molecules that exist in living cells and tissues. When illuminated with light of the proper wavelength, these fluorophores re-emit light at different, distinct wavelengths. The detection of a molecule's fluorescence spectra is evidence of the presence of that molecule, and the intensity of the fluorescence is dependent on the molecular concentration.

Tryptophan, an amino acid found in all living cells, is one of the key cellular fluorophores. When tryptophan is excited in the ultraviolet spectra region (~ 280 nm), it emits light at 340 nm. The detection of tryptophan emission is evidence of the presence of cells such as bacteria and cancers.

Professor Robert R. Alfano holds the seminal patents for the use of tryptophan fluorescence for the detection of bacteria in real time and for the detection of cancer.

The threat of bio-terrorism has greatly increased the need to detect bacterial spores as well as vegetative cells, according to Dr. Katz. Under hostile conditions of growth, two genera of bacteria, *Bacillus* and *Clostridium*, develop spores that are capable of surviving harsh environments for many years.

Spores can remain indefinitely in this state until more hospitable conditions occur, at which point the spores will germinate and form vegetative cells. Some of these bacteria are highly pathogenic. For example, *Clostridium botulinu,* is the causative agent in cases of severe food poisoning known as botulism, while *Bacillus anthracis* causes anthrax, which is highly lethal and a potential biological warfare weapon. An important constituent of spores, which is not present in vegetative cells, is dipicolinic acid (DPA), which can constitute 10% of the dry weight of a spore. DPA in spores can form chelates with calcium or other metal ions. These chelates have unique fluorescence spectra that can serve as a signature for the presence of spores. Researchers at the IUSL are investigating the native fluorescence properties of DPA and spores in order to develop methods to detect their presence.

Drs. Katz and Alfano will soon design, construct and test two prototypes, real-time fluorescence-based instruments to detect bio-agents. The first instrument is a point detector consisting of a compact spectrometer for collecting fluorescence spectra at multiple excitation wavelengths; data analysis algorithms to detect the "signatures" of bacterial cells and endospores; and a transmitter to issue a warning on a positive signal.

The second instrument will be a fluorescence imaging system that will build upon the results of the point detector. This unit will be able to scan larger areas with higher spatial resolution.

"We are optimistic about developing photonic technologies to detect bio-terrorism agents," Dr. Katz said. "We have built units for cancer detection and we believe that extending the concept to bio-agents will not pose insurmountable difficulties."

He added that the next step will be to field test the photonic based system to establish its sensitivity – the minimum concentration of bacteria needed to generate an alarm signal – and to minimize the number of false alarms.

DETECTING CHEMICAL AND RADIOACTIVE AGENTS

The overwhelming majority of material imported into the United States arrives via containers. The enormous number of containerized cargo units and truck trailers entering the nation daily, therefore, poses a security problem of major proportions.

Although techniques are available to analyze specific containerized units, the sheer number of units entering the country, coupled with the need to process and move the units on their way as quickly as possible, requires new methods to scan and monitor their contents rapidly.

Fiber Optic Sensor for Rapid Analysis and Screening for Radioactive and Chemical Materials in Containerized Cargo and Truck Trailers

A research project under the direction of Professors Harry D. Gafney and Nan-Loh Yang of Queens College and the College of Staten Island, respectively, is designed to meet this challenge. Their invention utilizes an optical fiber that can be built into containerized units or retrofitted into existing units to perform an initial "triage" for conventional explosives, radioactive emission and chemical weapons. The fiber can be checked easily at the port of embarkation through an external optical coupling, by plugging into the optical fiber with an external, hand-held unit. The stored information is then transferred to a dedicated PC through available technology for storage and/or transmission to the port of entry or encoded in a bar code that is affixed to the container or trailer.

Porous regions of the optical fiber are impregnated with polymer adsorbants. These, in turn, are doped with luminescent reporters whose emission lifetime and/or emission quantum yields are functions of the acidity of the medium and/or their local environment. The detector is capable of identifying explosives such as nitroglycerine and TNT, as well as plastic explosives and radioactive emissions, including beta and gamma emissions.

A major advantage of the method devised by Professors Gafney and Yang is that it incorporates the detector into the containerized unit, or truck trailer, thereby keeping it in close proximity to the contents and maximizing the probability of detection.

Sensing and Tracking Chemical/Biological/Radioactive Agents for Homeland Security Applications

Optical sensors are well suited to applications involving real-time sensing and tracking of chemical, biological and radiological agents. For tracking the agents in the atmosphere, remote sensing is preferred. In the case of protecting public water supplies, however, *in-situ* point sensing along the distribution network is preferable.

The Mobile laboratory houses the Lidar system.

City College's Optical Remote Sensing Laboratory has active research projects and capabilities for both atmospheric and water sensing for the detection of biological and chemical agents. They include:

- Stationary and mobile vertical multi-wavelength lidar systems for ranging of aerosols and water vapor in the atmosphere (to 20 km);
- A system to detect trace gas constituents of the atmosphere along a path of up to 2 km;
- Passive radiometers for atmospheric measurements; and
- Fiberoptic water quality sensors for *in-situ* measurement and characterization of suspended solids, dissolved organic matter, and bioactive organisms.

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