JSTO in the News

DTRA.mil

October 2024 | Vol. 14 No. 5

Shedding Light—and Weight

Farther Than the Eye Can See

DTRA MISSION

DTRA provides cross-cutting solutions to enable the Department of Defense, the United States Government, and international partners to Deter strategic attack against the United States and its allies; Prevent, reduce, and counter Weapons of Mass Destruction (WMD) and emerging threats; and Prevail against WMD-armed adversaries in crisis and conflict.

CHEMICAL AND BIOLOGICAL TECHNOLOGIES DEPARTMENT MISSION

Lead DoD science and technology to enable the Joint Force, nation, and our allies to anticipate, safeguard, and defend against chemical and biological threats.

DEFENSE THREAT REDUCTION AGENCY

Research and Development Directorate
Chemical and Biological Technologies Department
Joint Science and Technology Office
for Chemical and Biological Defense

8725 John J. Kingman Road, Stop 6201, Fort Belvoir, VA 22060

www.dtra.mil

Find us on social media: @doddtra

Front cover: Steve Adamshick, Associate Professor and Director of the Laboratory for Education and Application Prototypes at the Western New England University (LEAP@WNE), inspects an American Institute for Manufacturing (AIM)/Spark Photonics Education and Workforce Development (EWD) Photonic Integrated Circuit (PIC) chip. The EWD PIC kits have shifted how the university's integrated photonics curriculum will be taught in the future. They previously focused on the theory behind fundamental passive/active photonic components. The EWD PIC kits now enable teaching hands-on laboratory skills to accompany the theoretical foundation. (Photo courtesy of Western New England University)

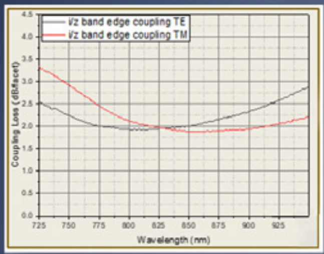
Inside cover: SSGT Nathan Hoskins, an airman assigned to the 423d Civil Engineer Squadron, uses a joint chemical agent detector during an exercise at RAF Alconbury, England. The exercise was geared towards training airmen on how to properly control and examine a contaminated area after a simulated chemical attack while in Mission Oriented Protective Posture gear. (U.S. Air Force photo by SSGT Eugene Oliver)

Back cover: U.S. Marines with the Advanced Infantry Training Battalion, School of Infantry-West, Hawaii Detachment face a simulated chemical threat while conducting a tactical movement during an Advanced Infantry Marine Course (AIMC), Kahuku Training Area, Hawaii. AIMC is advanced infantry training designed to enhance and test Marines' skills with a focus on reinforcing proper patrols and operational procedures. (U.S. Marine Corps photo by Lance Cpl. Terry Stennett III)

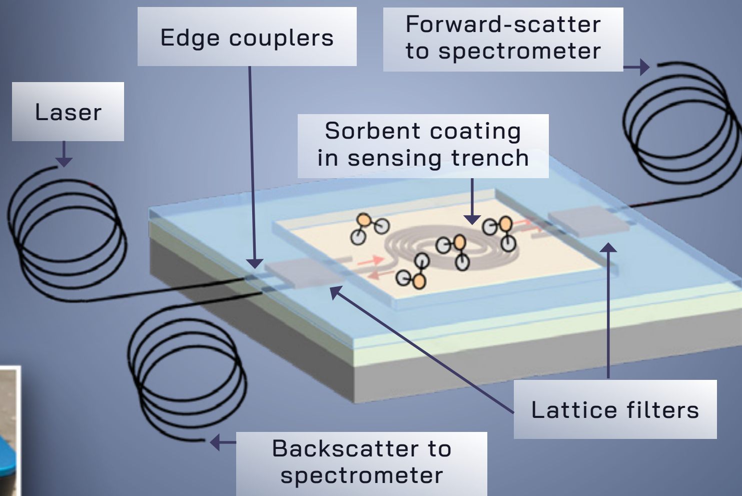
SHEDDING LIGHT AND WEIGHT

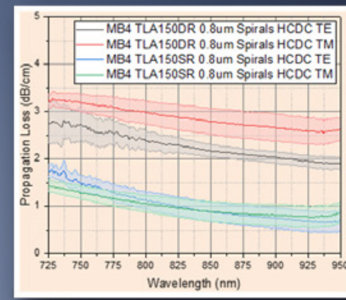
New photonic approaches for identifying chemical threats will lighten the load for accurate detection in the field.

As the nature of the threat landscape evolves, warfighters require capabilities that can be handheld and are low in weight and power so they can quickly detect and identify chemical threats. State-of-the-art microelectronic fabrication tools can produce low-cost photonic integrated circuits (PICs) that contain not only the sensing trenches for Waveguide-Enhanced Raman spectroscopy (WERS), but also other on-chip optical components such as filters and couplers. Raman spectroscopy is used in chemistry to provide a structural fingerprint or signature to identify molecules.



EDGE COUPLER LOSS

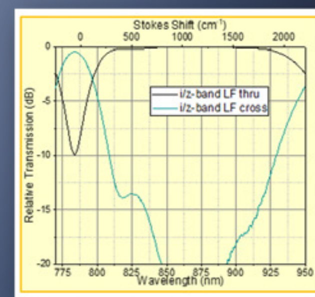




SENSING TRENCH LOSS

LASER AND SPECTROMETER

A WERS PIC for chemical threat agent detection, as well as the laser and spectrometer. (NRL image by Todd Stievater)

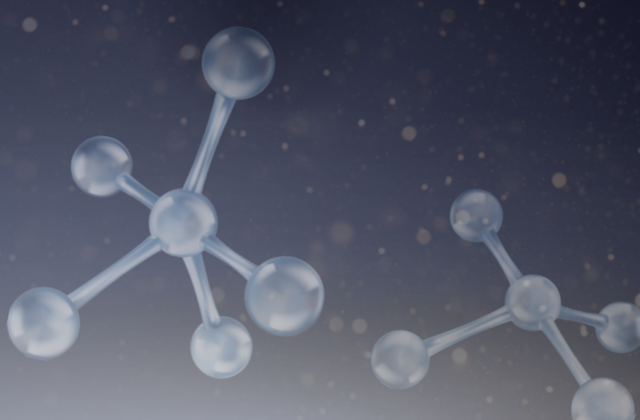


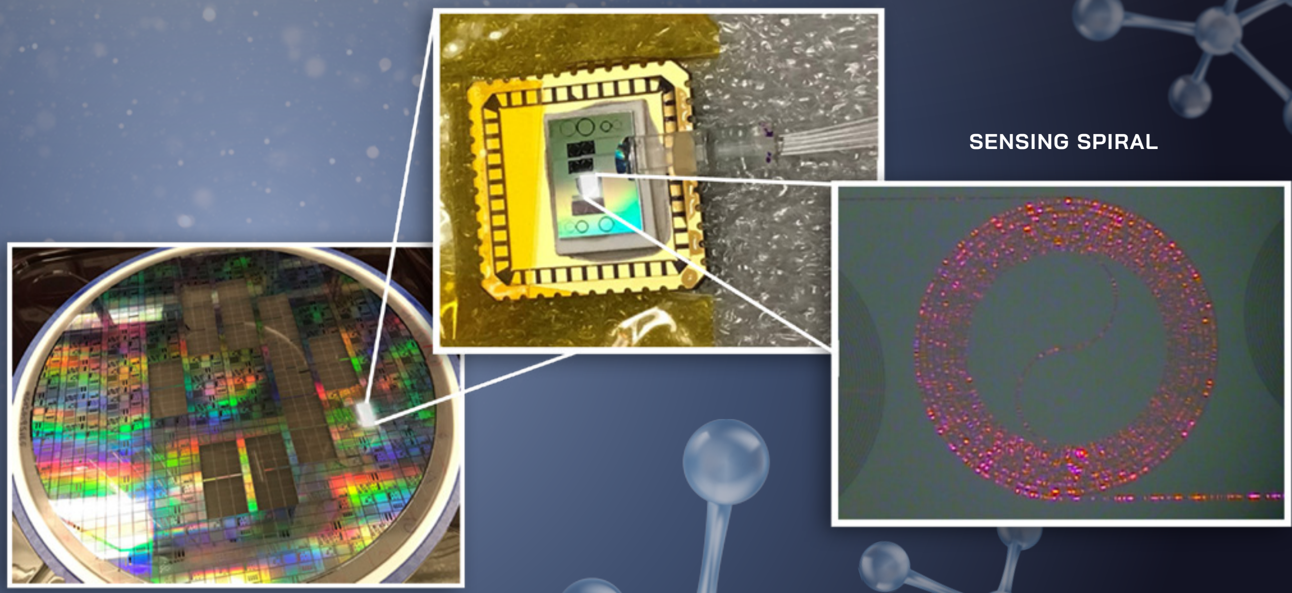
LATTICE FILTER TRANSMISSION

The Defense Threat Reduction Agency's (DTRA) Chemical and Biological Technologies Department in its role as the Joint Science and Technology Office (JSTO) for Chemical and Biological Defense, an integral component of the Chemical and Biological Defense Program, has invested in an effort with AIM (American Institute for Manufacturing) Photonics located at the State University of New York Polytechnic Institute, the Naval Research Laboratory (NRL), the Army Combat Capabilities Development Command–Chemical and Biological Center, the Army Research Laboratory, and the University of Rochester to develop this next generation of highly sensitive and selective chemical agent sensors based on photonics. These research scientists have been combining advancements in spectroscopy, semiconductor manufacturing, and polymer chemistry to create a new technology for handheld chemical threat detection.

These research scientists have been combining advancements in spectroscopy, semiconductor manufacturing, and polymer chemistry to create a new technology for handheld chemical threat detection.

WERS is a new form of sensing that uses sorbent polymers coated on evanescent nanophotonic waveguides to detect and identify low concentrations of toxic chemicals. While conventional Raman spectroscopy is effective in identifying liquids and solids, it fails to detect trace amounts of vapor due to weak optical interactions with small numbers of target molecules. WERS combines the long optical path lengths in photonic integrated circuits with sorbent polymers that selectively concentrate chemical threat vapors in the low part-per-billion range with fast sensor response.



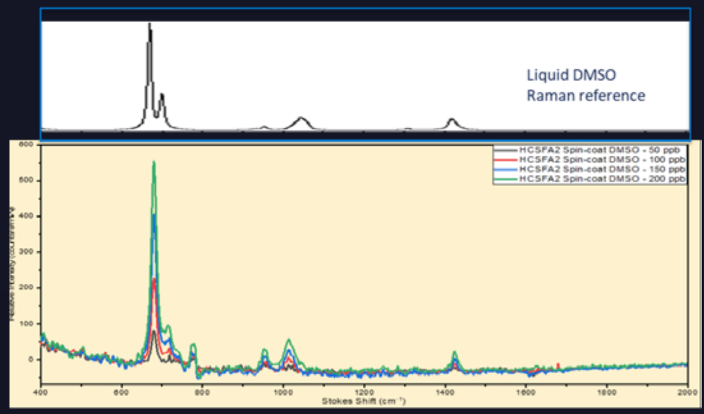


A 300-mm photonic integrated circuit wafer, a PIC assembled with optical fibers, and a sensing spiral for WERS. (NRL image by Todd Stievater)

WERS can identify target analytes based on a specific spectral signature.

AIM Photonics is a manufacturing innovation institute supported by significant DTRA JSTO investments to provide onshore manufacturing and assembly of PICs that are assembled with attached optical fibers at their test, assembly, and packaging facility. These PICs can then be coated with a sorbent polymer, which is designed to target a specific class of threat agent. The sorbent polymers are designed and synthesized at the University of Rochester. The use of 300-mm microelectronics fabrication and packaging ensures low-cost, high-yield production of these sensors in a U.S. foundry.

As a form of Raman spectroscopy, WERS can identify target analytes based on a specific spectral signature. Currently, scientists are testing prototype devices with chemical warfare agent simulants at varying concentrations to build new spectral libraries. And to enable simple plug-and-play operation with packaged WERS PICs, several commercial handheld spectrometer vendors are modifying their devices for WERS.

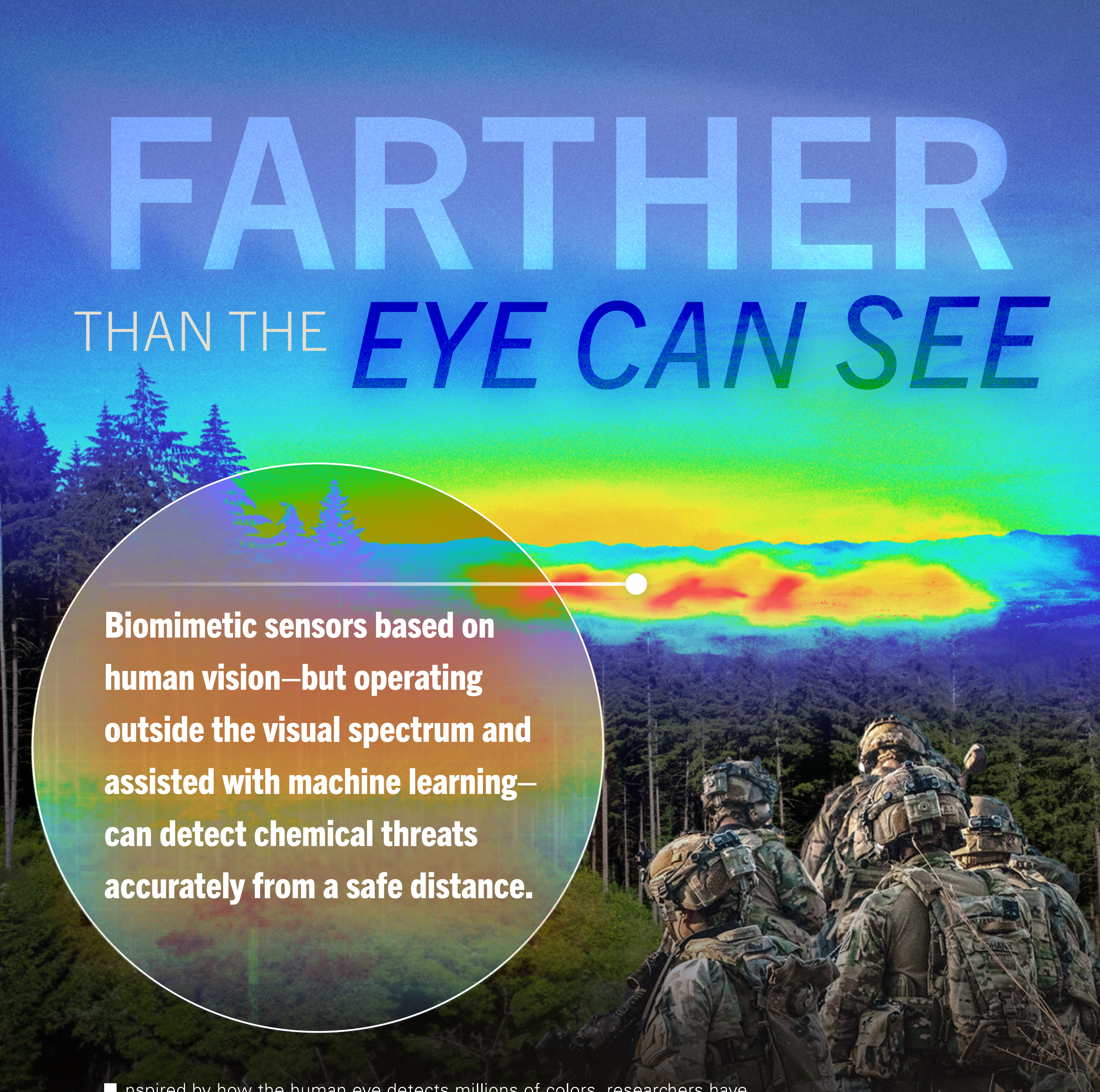


The WERS spectrum of dimethylsulfoxide (DMSO), a target simulant, shows a detection limit of approximately 10 parts per billion.

Future research and development efforts intend to decrease the size, weight, and power of these systems even further for a battery-powered handheld system that can detect and identify toxic chemical vapors at concentrations well below the permissible exposure limits to keep the Joint Force safe from chemical threats.

POC: Mr. Tyler Miller, tyler.c.miller23.civ@mail.mil

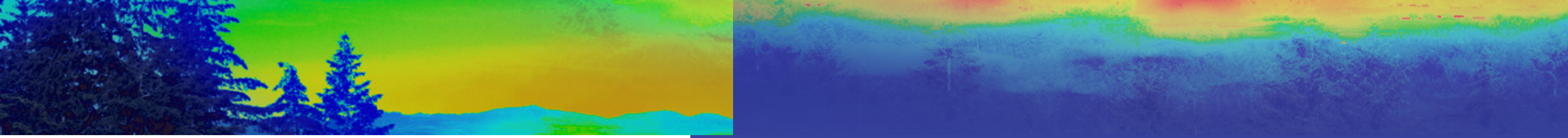
FARTHER THAN THE *EYE CAN SEE*



Biomimetic sensors based on human vision—but operating outside the visual spectrum and assisted with machine learning—can detect chemical threats accurately from a safe distance.

Inspired by how the human eye detects millions of colors, researchers have developed an infrared (IR) standoff sensor that is ultra-low in size, weight, power, and cost and can detect and identify a broad array of chemical threats.

Protecting warfighters from chemical threats requires systems able to quickly detect and identify hazards, even in complex environments with many chemicals and changing conditions. IR standoff sensors detect threats from a distance by capturing the unique IR signals of chemicals. This provides a crucial distance between the chemical threat and warfighters, which gives them time to either avoid the contaminated area or to don the appropriate protective equipment.

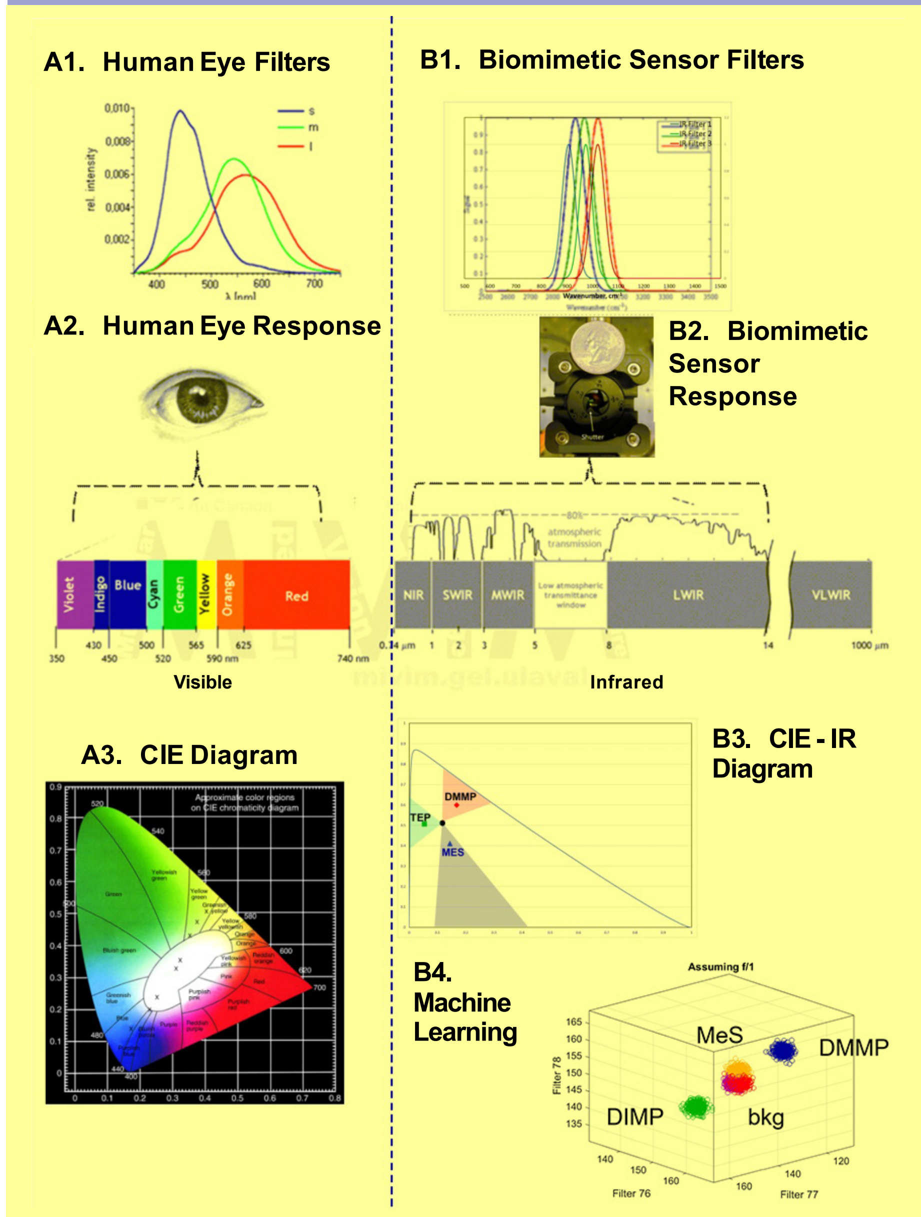


The traditional IR standoff systems are costly, fragile, require extensive training to use, and consume a lot of power, making them less than ideal for field use. To address these issues, the Defense Threat Reduction Agency's (DTRA) Chemical and Biological Technologies Department in its role as the Joint Science and Technology Office (JSTO) for Chemical and Biological Defense, an integral component of the Chemical and Biological Defense Program, partnered with researchers at the Naval Research Laboratory and the U.S. Army's Chemical Biological Center (DEVCOM CBC) to create a new, biomimetic IR standoff sensor. This sensor weighs under 1.6 ounces, uses minimal power, and is more affordable.

Traditional IR standoff systems operate by using thermal contrast between chemical compounds of interest and the background of the cold sky to generate an infrared spectrum of the threat agent. These new IR sensors provide a solution for standoff chemical detection systems that are less expensive, bulky, and complex to augment the capability. The sensor works like the human eye, which uses different light-sensitive cones to distinguish millions of colors. Instead of visible light, this sensor uses overlapping IR filters to identify chemicals by analyzing their molecular vibrations. By applying statistical detection and machine learning, the sensor can distinguish between harmful chemicals like nerve agent simulants and harmless background (bkg) chemicals. This technology ensures accurate threat detection.

The biomimetic sensor uses multiple IR filter/detector combinations to generate a response to a target chemical in the same manner that the human eye sees different colors. The human eye uses three light-sensitive cones composed of different visible optical filters/dyes for discriminating over 2.3 million discernable visible colors from blue to red in the visible spectrum. The key element of the filters is that they are broadband and overlap. The International Commission on Illumination (CIE) chromaticity

These new IR sensors provide a solution for standoff chemical detection systems that are less expensive, bulky, and complex to augment the capability.



Column A shows how the human eye differentiates color. Column B shows how the small biomimetic sensor (compared to a quarter) discriminates between different chemicals using the CIE-IR approach (B3) and the more traditional machine learning approach (B4). [NIR = near IR, SWIR = short-wave IR, MWIR = mid-wave IR, LWIR = long-wave, VLWIR = very long-wave IR] (Image by Ken Ewing, NRL)

U.S. Soldiers conduct a ruck march while wearing gas masks for a chemical, biological, radiological, nuclear exercise during European Best Medic Competition (EBMC) at Grafenwoehr, Germany. The EBMC tests competencies, skills, and readiness of European theater medics so they can respond more effectively and efficiently. The highest winners of the Joint Force are selected to represent the European region at Fort Liberty, North Carolina. (U.S. Army Reserve photo by Spc. William Kuang)

diagram describes how the eye perceives color over the visible spectral range. The biomimetic sensor uses the same mechanism as the eye to distinguish visible colors, however it operates in the IR portion of the electromagnetic spectrum, which provides molecular-level insight by probing bond vibrational modes. In the biomimetic sensor approach, three overlapping IR filters enable discrimination between different chemicals based on their IR spectral properties.

The DEVCOM CBC team used statistical detection algorithms and machine learning concepts to quantify the filter-conditional probabilities of detection and confusion between various threat and non-threat signatures, as well as to provide algorithms to predict the chemical identity. Machine learning results from this approach allow the biomimetic sensor to differentiate the chemical agent simulants dimethyl methylphosphonate (DMMP), diisopropyl methylphosphonate (DIMP), and methyl salicylate (MeS), as well as discriminate "threat" chemicals from common background interferents. Both methodologies demonstrate the inherent selectivity of the biomimetic sensor by modeling the system based on human color vision.

DTRA JSTO investment into the biomimetic sensor will ensure the capability for successful standoff detection of hazardous chemicals, such as nerve agents, for warfighters in the field. Because of its small size and weight and low power requirements, the sensor shows great promise for widespread applications throughout the Joint Force against chemical attack. ●

POC: Tyler Miller, tyler.c.miller23.civ@mail.mil

CBD S+T

CONFERENCE 2024

2024 Chemical and Biological Defense Science & Technology Conference
December 2-5, 2024
Fort Lauderdale, Florida

- @cbdstconference
- @dtrajstoengage
- @DoDDTRA
- CBD S&T Conference
- DTRA JSTO Engagement

Join thought leaders and experts from around the globe who are committed to making the world safer by confronting chem-bio defense challenges.

Register today at

CBDSTCONFERENCE.COM

Registration deadline: November 8, 2024

Within the Defense Threat Reduction Agency's Research and Development Directorate resides the Chemical and Biological Technologies Department performing the role of Joint Science and Technology Office for Chemical and Biological Defense, an integral component of the Chemical and Biological Defense Program. This publication highlights the department's advancements in protecting the Joint Force, our nation, and allies from chemical and biological threats through the innovative application of science and technology.

FOR MORE INFORMATION VISIT ONLINE

DTRA.MIL