SENSOR DOMINANCE: EXPLOITING PHOTONS FOR BIOLOGICAL AGENT DETECTION

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Sensor dominance, and especially biological agent sensing, is vital to the success of our military in the 21st Century.
An obvious statement, but what does sensor dominance really mean, and how will it impact future military operations in an increasingly complex world?
How is DARPA, and specifically my office, the Microsystems Technology Office, creating the technologies that will make sensor dominance a reality?
Good morning, my name is John Carrano, and I'm here to answer those questions with this talk on "Sensor Dominance: Exploiting Photons for Biological Agent Detection."

Imagine a night so dark you can hardly see your hand in front of your eyes.
On this night, a group of anxious infantryman are in defensive positions bracing for a possible enemy attack.
As the night wears on, the infantry unit has no indication of the danger at hand.
Suddenly, the darkness is pierced by tracer rounds, fired with deadly precision.
Within moments the entire defensive position is overwhelmed by what must have been a vastly superior force.
This is not the stuff of a Hollywood script.
It is a factual accounting of a British unit attacking an Argentinean infantry battalion during the Falklands campaign some twenty years ago.
The Brits were not superior in numbers, but they were superior in a key technology: thermal imaging sensors.
This is a classic example of sensor dominance in modern warfare: it was the first major use of infrared imaging sensors in combat; and, the results were staggering.
The British achieved a completely lop-sided domination of the night-time battlefield over the night-blind Argentinean forces.

In previous wars, we have certainly witnessed new weapons systems usher in a new era in warfare: the machine gun in World War I, or the tank in World War II are good examples.
But in many ways the Falklands War ushered in the age of sensor dominance in modern conflict.
However, on today's more complex battlefield, where the battlefield itself is amorphous, and our adversaries may range from traditional states to shadowy state sponsored terrorists, the threat of a small, relatively poorly equipped enemy launching a deadly blow against U.S. or coalition forces is a new reality in a new era of warfare.

Consider, for example, the potentially devastating effects that a small but well organized terrorist cell could have on our modern army if the terrorists attacked our forces with a small amount of a biological pathogen.
If not quickly detected, our forces could be seriously threatened, and our operations severely compromised.
Our challenge then, in this new age of conflict, is to ensure that U.S. and Coalition forces are capable of detecting and then defeating such asymmetric threats.
We must achieve complete sensor dominance over our enemies, much like the British achieved, but now in the newer context of emerging asymmetric, yet lethal threats, such as from biological agents.
Specifically, I will discuss over the next few moments how MTO is leading a revolution in the development of novel photonic components and integrated microsystems to enable an entirely new class of compact, reliable, and high-performance biological agent detectors.

The first phase in this revolution is the establishment of effective partnerships-collaborations with innovative minds at visionary companies-partnerships with people like you.
It is those of you in this audience that share with us this passion for excellence

who are bringing about the kind of technology revolution that MTO is spearheading. We are looking to the innovation and collaboration of our contractor base to help us answer the challenges before us-to make this transition into the new era of warfare.

One specific area of emerging opportunities is in optically-based bio-sensors. Although there are a number of different techniques for sensing biological pathogens, we are particularly interested in optically-based approaches owing to several potential advantages compared to other methods: such as, rapid response times-results in a matter of seconds, not hours; high sensitivity; high reliability with minimal maintenance; low cost; small form factor; and, low power consumption. These are significant potential advantages.

As with any technology, there are also potential drawbacks.
One possible detractor to optically-based sensors is that they don't provide good specificity owing primarily to limited spectral coverage.
This is the first challenge to solve.

In the Semiconductor Ultraviolet Optical Sources (or SUVOS) program we have already made great strides toward overcoming many of these limitations by increasing the number of spectral bands available to the sensor owing to innovations in ultraviolet laser diodes, UV light emitting diodes, and integrated microphotonics.

I've just described some challenges we are having success in solving.
Now I'll move on to problems we have yet to solve.
One of the most difficult challenges confronting sensors today-one that applies to virtually any sensor modality--is the unacceptably high false alarm rate.
Many biological pathogens share similar characteristics with harmless substances, so one needs to be able to discriminate distinguishing features of the agents from the background clutter.
This is a DARPA-hard problem we need help in solving.
The key to reducing the false alarm rate in a sensor is to determine the best set of signals that are most orthogonal to the background clutter.
In other words, one needs to be able to discriminate the signal you are looking for from the existing benign background.
For optically-based biological sensors, the ability to discriminate is in large part dependent on your ability to exploit the multispectral content of both the interrogating beam as well as the received return signal.
Other discriminators exist as well, such as the temporal behavior-that is, its behavior over time-as well as shape and polarization content.
All these elements enhance our ability to discriminate the species of interest from the background.
Thus, accessing as wide a portion as possible of the electromagnetic spectrum in a truly integrated microsystem configuration is essential to being able to discriminate agents of interest from the benign background clutter.

We are developing the key microphotonic technologies that will enable an entirely new class of bio-sensors based on an ultraviolet optical spectroscopy technique known as laser-induced fluorescence (or LIF).
The idea behind LIF is that certain fluorophore markers-that are known to be associated with biological species, such as anthrax-will fluoresce in certain wavebands when excited by deep ultraviolet radiation.
In other words, they will glow with a distinct color.
Although there are some bio-sensor systems today that perform detection using UV-fluorescence, they are limited in effectiveness owing to their dependence on large, power hungry, expensive and unreliable ultraviolet laser sources.
Furthermore, the fluorescence bio-sensors of today are constrained by a practical limitation of only one excitation wavelength of UV light.

As I described earlier, a key to reducing the false alarm rate of optically-based biosensors is the ability to exploit the multispectral content of the desired signals versus the background interferents.

The SUVOS program is developing chip-scale solutions to these limitations through the innovative design and fabrication of deep ultraviolet laser diodes and light emitting diodes (or LEDs) at the optimum wavelengths for the critical fluorophore markers of interest.
The invention of these new semiconductor UV sources thereby enables the design and construction of a new generation of biosensors.

Recall the tragic death of the Brentwood mail workers, and others, during the anthrax attacks in the fall of 2001.
Had early warning bio-sensors been in place these workers would have been alerted to the threat, and could have received life-saving treatment.
SUVOS is an important first step at preventing future catastrophes such as this.
What is still needed is to blend SUVOS capabilities with other functions to develop an truly integrated device.
The sensor's first task would be to determine with reasonable reliability whether a particle is likely to be a weaponized biological agent.
That is the role of the SUVOS program-to provide a high quality front-end queuing sensor (or trigger).

After the SUVOS sensor identifies a particle of interest, then we wish to isolate that particle along with any others that fit into that category.
So, what we want at this stage could be considered a sophisticated sorter that effectively enriches the concentration of particles of interest.
After the sorting and enriching of the sample occurs, we then want to perform additional spectroscopy on that assemblage of suspect particles.
A promising technique for identifying particular molecules and biological species is based on the science of ultraviolet resonance-enhanced Raman spectroscopy.

In this procedure, laser light at of the appropriate wavelength interrogates a sample.
As it turns out, molecules often possess distinctive Raman shifts with sharp spectral features that lend themselves to identification through pattern recognition algorithms.
As you can see, these technologies can work together to create an effective sensor capability.

So, our future interest is in developing this revolutionary device--an all optically-based biological agent sensor that can do continuous, real-time monitoring of an ambient environment and provide early warning of possible bio-threat events.
In addition, we want to be able to isolate those particles, and perform actual species identification, thus providing confirmation of an attack.
My goal would be for this system to be compact (meaning shoe-box sized), cost under $20K, have a response time of well under one minute, operate continuously twenty-four hours per day, and have a sensitivity of better than 10 agent containing particles per liter of air at a false positive rate of less than once per every six months.

To make this vision a reality-to actually construct this device-we need several key breakthroughs beyond the accomplishments of the SUVOS goals.
The first breakthrough we need is in particle sorting technology-the technique to actually pull particles of interest out of an air stream containing a majority of benign particles.
Secondly, we must develop compact and reliable very deep ultraviolet laser sources capable of operation between 245 nm to 250 nm as this is the optimum range for UV-resonance enhanced Raman spectroscopy.
And, finally, we need compact UV spectrometers to detect the Raman spectral fingerprints which will yield the species identification.
The key to all this is to recognize that miniaturizing one portion of the overall sensor is meaningless if other components remain bulky, expensive, fragile and unreliable.
In other words, we desire the integrated microsystem that Zach Lemnios spoke of earlier.
In MTO, we are interested in crafting a program that will develop the key enabling

components to make this vision a reality.

Once we have achieved this, we can leverage this accomplishment for even greater capabilities.
MTO is continually looking for ways to integrate more functions into smaller packages-so we would like to investigate the possibility of adding a capability to perform chemical sensing, as well as the detection of toxic industrial chemicals, and explosives.
It makes sense to merge biological and chemical sensors because the two are related, not withstanding some key differences.
The likely conops for such sensors are also very closely related.

The merging of different sensor modalities onto a unified platform is a significant goal, which in turn presents the next challenge: the ability to couple different spectroscopic techniques into a single integrated microsystem employing compatible photonic, electronic, and MEMS technologies.

What I would like to leave you with this morning is that at the heart of achieving sensor dominance is the invention of new materials and devices-and new ways to integrate them.
In the SUVOS program, we are working in these areas to create dependable, affordable, deployable technology that will save lives from deadly biological pathogens such as anthrax.
Although the SUVOS program has met with much success in developing a new class of bio-sensors, I see a new set of challenges that will require new MTO programs to solve.
If you have ideas on any of these challenges, I'd like to talk with you-stop by our booth or give me a call.
Thank you very much.