Transport of Photonics "Sniffer" Sensor into High Hazard Zone

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Abstract

There is a need for a reliable explosive detection system that provides quick, accurate results in all types of conditions. To maximize performance, the system needs to focus on detecting the explosive material without being impacted by interferents such as pesticide, fertilizer, or diesel fuel.

Typically, trained canines have been used to detect explosive materials. They use their sense of smell to detect the minute amount of vapors given off by the explosive material.

For this experiment, we investigated the use of a biophotonic sensor that could "sniff" the air near the site to detect the presence of possible explosive material. We also designed, built, and programmed a robot that could transport the sensor into the high hazard zone.

The robot we designed was able to remotely drive up to a testing site, expose our chip, and then return. We found that the infrared sensor on the robot and the remote controller only had a limited range (approx. 15 feet). The sensor we fabricated was able to detect the explosive material's vapor at different temperatures and concentrations (256 ppb @ 23˚C to 14 ppm @ 58˚C).

Previous Testing

The Reinhard Lab previously studied this concept using nanoparticle cluster array sensors to detect trace amounts of the explosive material 2,4-dinitrotoluene (DNT). They used surface enhanced Raman spectroscopy (SERS) to measure the effectiveness of the sensor to detect various concentrations of DNT vapor. In order to enhance the performance of the sensor, a 10 mM solution of sodium hydroxide (NaOH) was sprayed onto the surface of the sensor. The NaOH solution on the sensor's surface helps to "capture" the vapor molecules from the explosive material. From their previous testing, they were able to detect concentrations as low as 10 ppt.

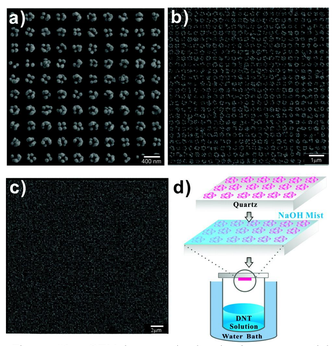


Figure #1 - SEM images (a, b, c) of a nanoparticle cluster array (NCA) (d) Sample preparation: the NCAs are wetted with an aqueous NaOH mist and exposed to DNT vapor at a defined concentration, which is controlled by the DNT concentration in the aqueous solution contained in the glass chamber at 25 ˚ C.

Their previous work also tested the effectiveness of the sensor when other interferents (e.g., diesel fuel, fertilizer, and pesticide) were present in the explosive material's vapor. They found that their sensor was still able to detect the explosive material's vapor.

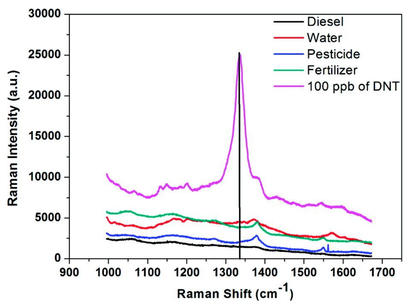


Figure #2 - SERS spectra of DNT vapor at a concentration of 100 ppb and potential interferents (diesel, water, pesticide, fertilizer vapor) at 25 ˚ C.

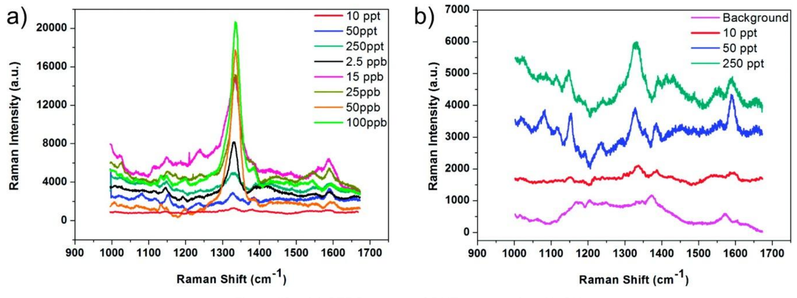


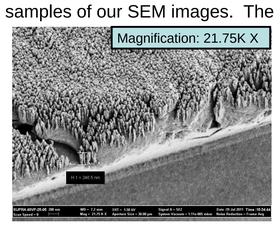
Figure #3 – (a) SERS spectra of DNT measured on NaOH activated NCAs for concentrations between 100 ppb to 10 ppt. (b) Magnified view of the 250, 50, and 10 ppt spectra.

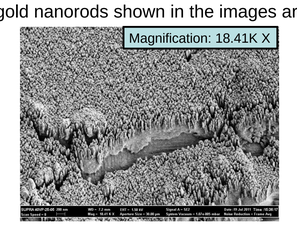
RET Testing Program

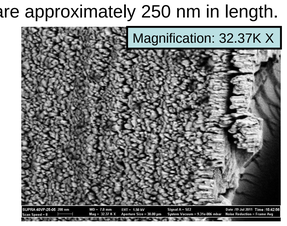
For our experiment, we built off the work the Reinhard Group had previously performed. We incorporated the following modifications to our sensor chip's design:

- Chip's substrate was silicon instead of quartz.
- Detection surface of our chip was gold nanorods deposited at an oblique angle instead of cluster arrays.
- Changed the temperature of the DNT vapor.
- In one case, exposed the chip to a more real-world condition in room PHO903.

After fabricating the chips, we inspected them using the surface scanning electron microscope (SEM). Here are samples of our SEM images. The gold nanorods shown in the images are approximately 250 nm in length.







After inspecting our chips, we sprayed the surface with a NaOH solution and then exposed them to the different DNT samples for 4 minutes. We varied the following items for our DNT samples:

- Temperature from 0˚C to 58˚C
- Concentrations from 15 ppb to 14 ppm

Once the chip was exposed, we took measurements using a SERS to determine the effectiveness of the chip to detect trace amounts of DNT vapor. The following graphs present our results.

This graph displays our results for three different temperatures. Notice the "spike" occurring around 1350 cm^{-1}. This represents the "detection" of the explosive material's vapor. The "spike" is smaller for the lower temperatures because the vapor pressure is reduced. Approximate concentrations: 40˚C - 2ppm, 50˚C – 6 ppm, and 58˚C – 14 ppm.

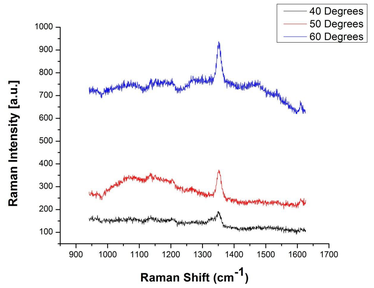


Figure #4 - SERS spectra of DNT vapor at different temperatures.

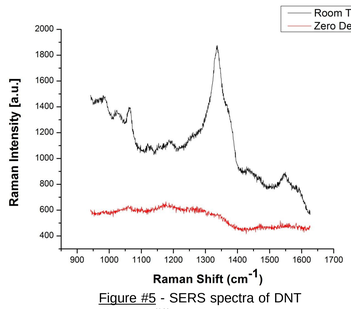


Figure #5 - SERS spectra of DNT vapor at different temperatures.

This graph also presents our results for two different temperatures. Notice the strong "spike" associated with the room temperature (23˚C) reading, but not for the measurement taken at 0˚C. One reason for the larger "spike" is thought to be as a result of that sample being at equilibrium. Approximate concentrations: 23˚C – 256 ppb and 0˚C – 15 ppb.

This graph displays the effectiveness of our chip to detect an explosive material in room PHO903 under "real-world" conditions. Our July 27th testing showed we were able to detect the explosive materials, but we couldn't repeat the results on August 3rd.

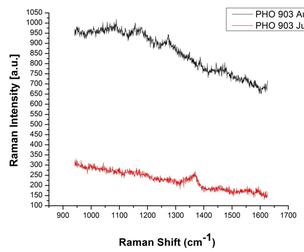


Figure #6 - SERS spectra of DNT vapor within PHO903 on two dates

RET Robot Design

Another aspect of the RET project involved designing, building, and programming a robot that can be used to transport the sensor into a high hazard zone. For our robot we used the Lego Mindstorm NXT kit. We found the design of a remotely controlled car using the Lego kit and an infrared receiver sensor from the HiTechnic website. We programmed the robot using both Lego NXT 2.0 and LabView 2009 software. Approximate cost of our robot is $400.

After building the basic car, we modified it to carry one petri dish where the sensor could be stored until the car reaches the site of the potentially explosive material to be tested. Once the robot arrives at the test site, a motor on top of the car lifts the cover off the petri dish and exposes the sensor to the material. After the sensor has been exposed for the specific period of time programmed, the motor lowers the cover onto the petri dish. The car is guided out of the hazardous zone.

During the testing of our robot we discovered that the infrared receiver and remote controller have a limited range of approximately 15 feet. Also, the tires and suspension of the robot restrict its ability to travel over non-smooth surfaces.

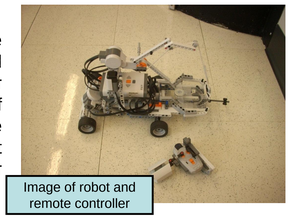


Image of robot and remote controller

Conclusions

As a result of our testing, we made the following conclusions:

- Our sensor was able to detect different DNT concentrations over a range of temperatures.
- We needed to be more careful when measuring our "background" because the wide variety of measurements impacted our results.
- The amount of the NaOH solution on the chip and its drying time had a major impact on the quality of the measurements. Suggest investigating other materials besides NaOH that can be applied to the chip's surface that would "capture" the explosive vapor molecules.
- We were not able to test the effectiveness of the chip at different distances. Future testing should investigate this aspect of the chip's performance.
- Should explore the possibility of building a larger robot that can carry a portable SERS for real-time reporting of data.

References

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Boston University Biophotonics Research Experiences for Teachers
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