ObservatoryNANO

BRIEFING No.11

SEVENTH FRAMEWORK PROGRAMME

SECURITY

NANOSENSORS FOR EXPLOSIVE DETECTION

The spread of terrorist events over the globe in the last decade has emphasised the importance of detecting concealed explosives and led to calls for new advanced technologies to protect the public. Because most explosives release little vapour, it is not possible to detect them effectively by methods widely used on other chemicals.

Detecting explosives is a very complex and costly task because of a number of factors, such as the wide variety of compounds that can be used as explosives, the vast number of deployment means, and the lack of inexpensive sensors providing high sensitivity and selectivity simultaneously. High sensitivity and selectivity, combined with the ability to lower the production and deployment costs of sensors, is essential in winning the battle on explosives-based terrorism.

Nanotechnology based sensors have strong potential for meeting all the requirements for an effective solution for the trace detection of explosives. This BRIEFING outlines the social and economical relevance of nano-enabled technologies for the detection of explosives in security applications, provides background information on the technology, and highlights further challenges to be addressed.

The need for explosive detection

The use of explosives by terrorist organisations has increased dramatically in recent years. In 2009 4350 of a total of 10999 terrorist attacks were undertaken using explosives. Over 10000 people were killed worldwide and more than 20000 were injured as a result of these attacks. The number of suicide bombings has increased by approximately 50% since 2005 [1].

Explosive devices such as conventional bombs, grenades or Improvised Explosive Devices (IED) are one of the most common weapons both in military conflicts and terrorist attacks. For terrorist organisations and insurgents, the IED has become a weapon of choice. These devices are being used to kill or harm civilians and military personnel as well as destroying vital infrastructure and assets. They are easily detonated from remote locations or by suicide bombers. As they can take different forms and be delivered to their targets in a variety of ways, these devices are proving difficult to detect. Efficient detection of hidden explosives and their components in luggage, mail, vehicles, aircraft, as well as on suspects is the grand challenge for law enforcement agencies throughout the world.

Trace-based explosives detection systems currently in use have limitations in selectivity, sensitivity, size, and certainly cost. Miniaturisation of systems to bench top or even handheld levels has great potential, especially for trace explosive detection. Recent advances in nanomaterial research provided a strong potential to create sensors for detecting explosives providing sensitivity at the single molecule level.

Nano-enabled technologies for explosives vapour detection

The research and development studies in the area of nanomaterials have demonstrated the ability of nanostructures to function as sensors of various chemical and biological compounds including explosives. Ultra-small devices with high sensing capabilities are among the key promises of the nanosensor domain[2]. **Electronic noses, nanowire/ nanotube and nanomechanical devices** are nanosensor concepts with the strongest potential to form viable technological platforms for trace explosive detection.

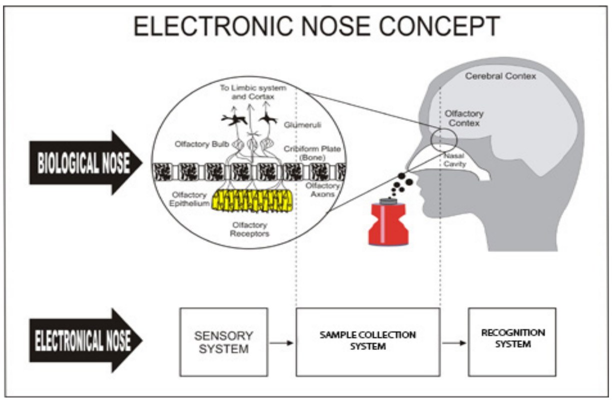

Figure 1: *Electronic nose concept*

At present, dogs have been trained and used successfully for sniffing out hidden explosives; however, dogs are expensive to train and are easily tired. The **electronic nose** technique can mimic the bomb-sniffing dogs without their drawbacks. An electronic nose device is usually composed of a chemical sensing system, sampling system and a pattern-recognition system, such as an artificial neural network (***Figure 1***).

The sensing system consists of an array of sensors, with each sensor in the array giving a different electrical response for a particular target vapour introduced into the sensing chamber. The combined output from the sensor array forms a fingerprint, or signature, that is unique for a particular odour. Pattern recognition techniques based on principal component analysis and artificial neural networks were developed for learning different chemical signatures.

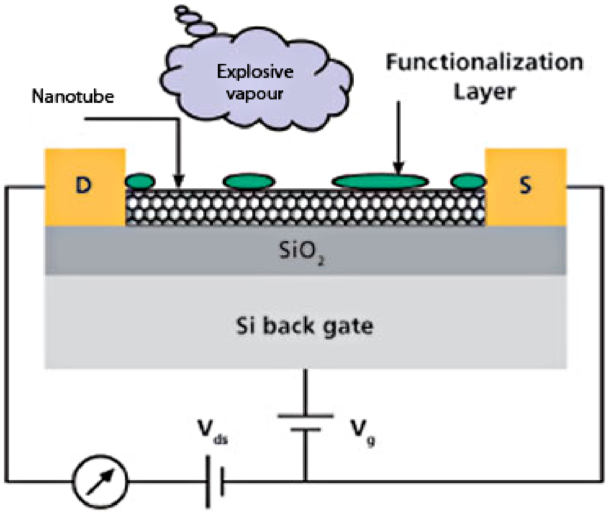

Figure 2: *Illustration of nanowires sensor platform.*

Nanostructures such as carbon and organic nanotubes (NT), **nanowires** and nanotubes have a very high surface area to volume ratio and unique electrical and optical properties that can be exploited for highly sensitive molecular adsorption detection. For instance (***Figure 2***), electrical conductivity in a nanotube changes drastically due to interacting with molecules of an explosive analyte, as a result of highly selective adsorption[3].

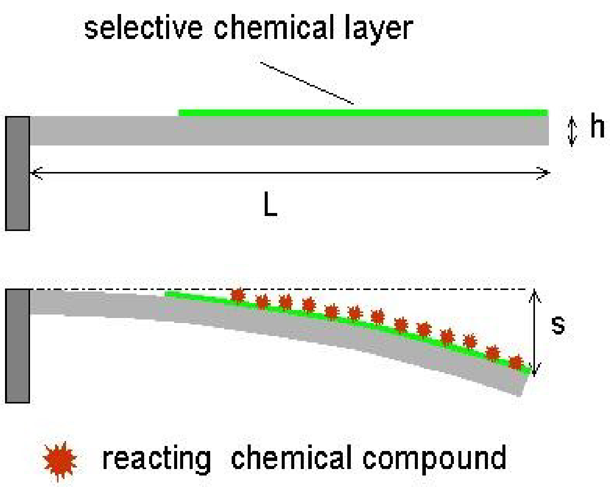

Figure 3: *Molecular adsorption induced bending a cantilever.*

Nanomechanical effects induced by molecular adsorption offer unprecedented opportunities for trace explosive detection. **Nanomechanical sensors** such as cantilever beams have many modes of operation[4]. For example, when explosive molecules bind to the detection molecules on the cantilever made in nano-structured silicon , this will induce a surface stress and the cantilever will bend (***Figure 3***). Differential adsorption is obtained by immobilising a selective layer on one side of the cantilever. Nanocantilevers are expected to provide ultra-high-sensitivity mass detection, ultimately approaching the single-molecule level[5].

Impacts

Impact on European Citizen

The deployment of new security technologies based on novel nano enabled explosive detection devices will serve to better protect European citizens against further acts of terrorism. However, there are some health hazards considerations associated with subjecting passengers to some types of screening technologies currently used for explosive detection. For example, certain types of explosive detection screening equipment may expose individuals to mild radiation. The use of explosive detection systems based on nanosensors will help to reduce the above mentioned implications posed by existing scanning equipment.

Economic/Industry

Though nanotechnology is also implied in some screening technologies (e.g. X-rays, IR), the really promising and developing sector is that of nano enabled sensors, which will provide advanced sensitivity and selectivity of explosive detection systems and does not seem to present the issues induced by screening.

Several drivers, primarily stemming from new regulations to address the threat of terrorism, drive the expansion of markets for explosive detection equipment. The direct economic impact of nanotechnology sensors for explosive detection can be seen in the formation of new companies to exploit these technologies (such as Owlstone Nanotech and Xsense). Assuming commercialisation challenges can be overcome, the greater effectiveness of nanotechnology-based approaches is likely to see them gain a market share from traditional approaches, whilst lower costs open up new application areas.

There is strong dual use potential, besides security applications in person and possession controls in public places, most nano enabled systems also have potential to be used for industrial process control in production of explosives and for explosive gas monitoring in mining industry.

The deployment of nano enabled explosive detection systems will add to the indirect economic impact, in which reducing the incidence of terror attacks also reduces direct social and economic impacts, such as disruptions to world trade.

Technology readiness levels

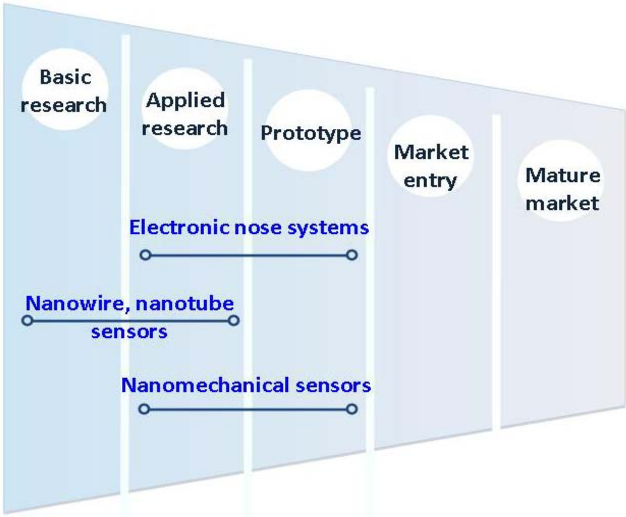

Figure 4: *TRL for nano-enabled sensor technologies for detection of explosives.*

Challenges

Most of existing technologies that utilise nanowires and nanotubes in the fabrication of sensors have fallen short of controlling the growth of the nanoparticles of a given size with minimal defects and the capability to manipulate and align these nanowires based on the application. Also, the characterisation of the material properties as a part of the device remains mainly unaddressed by current technologies[6] .

Challenges to unlock the potential of the electronic nose technology for viable explosive detection applications relate to providing stability, sampling and reliable calibration and identification of patterns in complex changing backgrounds. Combining nanosensors with advances in conventional detection platforms (e.g. electronic nose concept) seems to be the most promising approach for the development of advanced solutions.

In addition to technical challenges for developing novel nano enabled detection methods there are several overarching operational and policy considerations impacting the deployment of these technologies for protecting public from terrorism threats. Specifically, 1) the roles and responsibilities of multiple national, local and private stakeholders could impact how explosive detection technologies are funded and implemented in public places such as, for example, transport hubs and tourist attractions; 2) explosives detection technologies should be just a component of a layered approach to security, where multiple security measures are combined to form the overall security environment; 3) cost and potential legal implications have to be important policy considerations when determining whether and how to use these technologies.

Health & Safety

Environment, Health & Safety aspects of nanosensors for explosive detection have been considered by the ObservatoryNano[7]. Nanomaterials included in these technologies are generally bound to a substrate in which they are used in very small amounts per sensor. They are unlikely to be released during normal use of the applications. While exposure to nanomaterials can occur during the manufacturing stage especially if unbound/free nanoparticles are handled, it is however unlikely that human or environmental exposure would occur during use of the nanotechnology based sensors.

EU Competitive Position

Governments in all regions of the world have now realised the significance of the threats posed by illicit use of explosives and responded by increasing support of R&D activities aimed to significantly improve the explosive detection capability to prevent and respond to existing and potential threats. In 2008 the EU Council has adopted the EU Action Plan on Enhancing the Security of Explosives. The Action Plan[8] is built on three pillars, prevention, detection and response, containing specific measures on explosive precursors, the supply chain (storage, transport, traceability) and detection. A set of 48 specific horizontal actions, along with deadlines for their implementation concerning public security, complements and consolidates the three pillars. Funding is made available for measures falling under the Action Plan by way of two programmes: the Prevention of and Fight against Crime programme[9] and the 7th Framework Research Programme.

Our analysis of publications and patents and qualitative responses from experts have shown that EU research is complementary to the US for chemical and explosives detection.

The experts have also agreed that although Europe has existing sensor deployment for explosives detection relatively better than other world regions it lacks the appropriate level of support for technology transfer required for future leadership. The measures included in the Action Plan, in particular, funding research and industry collaboration under the FP7 and national programmes constitute a part of the EU response to this issue.

Examples of EU funded collaborative projects for the development of nano enabled technologies include:

- **HAMLeT** (PASR[10], 0.32M€ 2006-08),
- **GUARDED** (JIP-FP, 3.5M€, 2008-11),
- **DOTSENSE** (FP7, 1.9M€, 2008-11),
- **OPTIX** (FP7, 3.3M€, 2008-12),
- **S3** (FP7, 2.14M€, 2009-12),
- **PREVAIL** (FP7, 4.3M€, 2010-13),
- **COMMONSENSE** (FP7, 4.77M€, 2011-13).

Also, two European networks, CREATIF and NDE have been created to provide a communication platform for technology users and decision makers, providers and testers to discuss the future development of testing and to support user decisions and product / service development.

Summary

- The risk of a terrorist attack involving use of explosives remains high in Europe. These attacks may cause severe consequences including human casualties, and widespread disruptions of critical infrastructures and public confidence.
- Nanoscale effects can be exploited to offer the possibility of sensors that satisfy all the requirements for explosives trace detection. High sensitivity and selectivity, combined with the ability to lower the production and deployment costs of sensors, is essential in winning the battle on explosives-based terrorism.
- Explosive detection with high sensitivity and selectivity is a difficult challenge because of a number of operational factors, such as the acute shortage of explosive molecules that can be collected in a reasonable time and lack of selectivity because of interference from other molecules.
- Recent advances in nanomaterials research provide good potential to create sensors for detecting explosives providing sensitivity at the single molecule level. Also, due to reduced dimensions, nanomaterials offer capability of incorporating multiple sensors capable of detecting multiple threats simultaneously.
- The ability of nano enabled technologies to effectively detect explosives on people and their belongings, as well as the expectations of the public for openness and speed will likely be key drivers for their successful implementation.
- The direct economic impact of nanotechnology sensors for explosive detection can be seen in the formation of new companies to exploit these technologies.

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