Nanotechnology to Aid Chemical and Biological Defense

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Series A: Chemistry and Biology

Nanotechnology to Aid Chemical and Biological Defense

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Preface

The NATO Science for Peace and Security (SPS) Programme has identified the need to “facilitate mutually beneficial cooperation on issues of common interest, including international efforts to meet emerging security challenges”. An Advanced Research Workshop (ARW) was held on “Nanotechnology to Aid Chemical and Biological Defense” on September 22–26, 2014, in Antalya, Turkey, to address the NATO SPS key priority of *Defense against CBRN Agents and Environmental Security*. The ARW was co-organized by researchers from the USA and Georgia. Speakers and other participants came from the USA, Georgia, Italy, Germany, Belgium, France, Turkey, Croatia, UK, Slovenia, Ukraine, Moldova, Romania and Kyrgyz Republic. This book is representative of the scientific contributions made at this meeting emphasizing both fundamental research and practical implications of the research to CBRN defense and environmental security.

In Chap. 1 the potential of Atomic Force Microscopy (AFM) to characterize the nanoscale properties of pathogens such as *Candida*, *Aspergillus* and *Staphylococcus* species is elaborated, with AFM operated in various modes. Microbial pathogens are highly complex and heterogeneous systems, exhibiting differences in growth rate, as well as resistance to stress and drug treatment. The authors show that using topographic imaging, one can visualize the ultrastructure of live cells and their subtle modification under activity of antimicrobial agents. AFM can be operated under force spectroscopy mode with tips functionalized by biomolecular ligands to probe the localization and adhesion of single receptors on cells, such as cell adhesion proteins and antibiotic binding sites. They show that single-cell force spectroscopy can be used to quantify the forces driving microbe-microbe, microbe-solid and microbe-host interactions.

Chapter 2 summarizes experiences in the development of bacteriophage-based therapeutics, prophylactic and diagnostic preparations and their uses in different fields, such as medicine, veterinary, agriculture, food and water safety, etc. Bacteriophages are obligate intracellular parasites that are highly specific to their host pathogens. With the rise of antibiotic-resistant organisms, bacteriophages are beginning to be explored to target and treat multidrug-resistant pathogenic bacteria. The nanoscale of bacteriophages and the ease of implementing genetic modifications have made bacteriophages attractive biosensors for pathogen detection with high levels of reliability, sensitivity and selectivity with short assay times. Bacteriophage-based therapeutics which is still at early stages of development is discussed in this chapter. An important application of bacteriophages to environmental and thereby economic security is addressed in Chap. 3. It is shown that bacteriophages specific to *Xanthomonas vesicatoria* strains spread in Georgia can be used to efficiently prevent tomato bacterial spot in laboratory conditions under artificial infection. This finding and approach are of critical significance to the agricultural sector in many countries. Chapter 4 describes phage display as a way for identifying monoclonal antibodies for diagnostic purposes, especially in dealing with toxic and non-immunogenic antigens. The author shows that panning large phage libraries can be performed directly on whole cells to identify antibodies that will recognize their membrane-bound antigens in their native conformation and lipid environment. This opportunity is particularly meaningful when it is necessary to isolate antibodies that are able to bind accessible epitopes in vivo, as it is the case of biomarkers exposed at the cell membrane surface of pathogenic microorganisms. The author also suggests strategies useful to overcome common drawbacks of phage display technology.

The authors of Chap. 5 are concerned with environmental security threat posed by contamination of water sources by nanomaterials. They have conducted studies using model membranes to explore whether nanoparticles disrupt the membrane structure which would make them cytotoxic and what characteristics of nanoparticles may determine the mode and mechanisms of their interactions with membrane systems. Of special interest is the use of quartz crystal microbalance with dissipation monitoring as a technique to extract nanoscale information regarding nanoparticle-membrane interactions. Chapter 6 advances in detail an inexpensive bioassay suited for assessing chemical poisoning in the environment such as the presence of pesticides and other organophosphates, metal contaminants or nanoparticles. The authors show that their test with terrestrial isopods, a single species test, is flexible in terms of exposure duration and biomarker selection. By alternating test duration, one can assess the toxic potential of substances as low, moderate or high, while a variety of biomarkers at different levels of biological complexity increase the relevance of test results. Another instrumental approach, the electroanalytical method, to look at the toxicity of nanomaterials in the marine environment is described in Chap. 7. The method is shown to be advantageous for studying different biogeochemical processes in the marine environment, especially those related with organic matter, sulphur species and trace metals cycling and the interaction and distribution between dissolved and colloidal phases.

Chapter 8 describes a novel procedure based on metal oxide nanotubes to detect ultra-trace quantities of the explosive pentaerythritol tetranitrate (PETN). The inexpensive, lightweight, easily made and cost-effective devices are shown to detect PETN down to about 112 ppt. The authors provide a step-by-step description for the synthesis of anatase titanium dioxide nanotubes grown by electroless deposition under aqueous conditions in ion track-etched polycarbonate templates. Details of sensor construction on a chip are also provided. The synthesis of another type of nanomaterial, graphite-like carbon nitride, that can be employed as a catalyst for agent inactivation or as a chemical sensor is described in Chap. 9. Carbon nitride is a unique material because of the possibility to dope its structure by non-metal atoms though which one can impart novel chemical and electronic characteristics. The authors describe their development of a new method of pyridine pyrolysis to obtain O-doped graphite-like carbon nitride with high contents of oxygen. The authors of Chap. 10 report on citrate-capped, colloidal gold nanoparticle (AuNP) film assemblies of varying particle sizes (5–50 nm) adsorbed to bulk Au substrates to serve as platform electrochemical sensors to simultaneously detect and reduce the explosive trinitrotoluene (TNT) to 2,4,6-triaminotoluene (TAT) in solution. The high surface area-to-volume ratio of colloidal AuNPs offers advantages in electrocatalysis and enhanced signal transduction, while the facile immobilization onto a variety of substrates provides an adaptable and reproducible platform technology.

Material advances in the synthesis of chalcogenide material are discussed in Chap. 11. These novel class of materials are good candidates for photonic and optoelectronic applications such as optical elements and memories, optical sensors, nonlinear optical devices, holographic elements, IR telecommunications, biosensing and signal processing applications because they possess high strength/hardness, excellent wear/corrosion resistance and excellent optical properties (high refractive index, high transmittance in the near IR and IR regions of the spectrum). The report focuses on the characterization of chalcogenide incorporating tin and describes changes in measured properties as a function of tin content. In Chap. 12 another important type of porous material, zeolitic imidazolate frameworks (ZIFs), is described. They are promising materials for use in the capture and/or detection of hazardous chemicals under humid environments. In this work molecular simulations have been carried out to find a suitable ZIF structure to handle one explosive (nitromethane), six toxic chemicals (hydrogen disulphide, sulphur dioxide, nitrogen dioxide, carbon monoxide, ethylene oxide, benzene) and three warfare agents (sarin, sulphur mustard, phosgene oxime). Super-resolution imaging using fluorescent labels to image nanoscale biomolecular structures is discussed in Chap. 13. The authors propose the development of a super-resolved stochastic hyperspectral Raman microscopy technique for imaging of biological architectures. The surface-enhanced Raman spectroscopy (SERS) signal contains information about the presence of various Raman bands, allowing for the discrimination of families of biomolecules such as lipids, proteins and the DNA. The last chapter chronicles the lingering effect of radioactive wastes in soil and water in the former Soviet Republic, Kyrgyzstan. The paper presents an assessment of the radioactive material threat in soil and water sources in all parts of the country.

The Advanced Research Workshop also included a few presentations that are not included in this book: cantilever-based sensors for detecting *E. coli* O157:H7, waterborne parasites, food and water toxins and *B. anthracis*; nanomaterials-based chemical sensors, many utilizing metal oxides in the form of thin films, nanoparticles and nanotubes; and the development of gas sensors based on nanowire bundles exploiting both the chemiresistor and surface ionization configurations.

The Advanced Research Workshop brought together a diverse group of international civilian researchers focused on nanoscience and nanotechnology problems that are relevant to chemical and biological defense needs, in order to share current state of the art and discuss future opportunities and challenges. The workshop and this resulting book have provided many examples of nanomaterials and nanotechnology having the potential to be used for detection and decontamination of chemical and biological threat agents and in the development of protective technologies. These capabilities are of increasing importance to international security, as chemical and biological agents begin to be used more frequently in acts of terrorism, in ways in which we have not previously been able to respond effectively. Cooperative research among NATO countries and NATO partners, as represented in this Advanced Research Workshop and this book, can make a critical contribution to meeting these challenges.

Worcester, MA, USA Terri A. Camesano

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