NANOSENSORS BASED ON METAL AND COMPOSITE NANOPARTICLES AND NANOMATERIALS

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Content

1. Introduction
2. Metal nanoparticle sensors
   2.1 Magnetic Nanoparticle Sensor
   2.2 Noble Metal Nanoparticles
3. Carbon nanotube sensors
   3.1 Carbon Nanotube Gas Sensors
   3.2 Carbon Nanotube Sensors
   3.3 Carbon Nanotube Biosensors
3.4 Carbon Nanotube/Polymer Composite Nanosensors
4. Microcantilever sensors
5. Bionanosensors
   5.1. Optical-Based Nanosensors
   5.2. Nanoscale Sensing Systems
   5.3. DNA-Based Sensors
   5.4. Protein-Based Sensor
   5.5. Redox-Based Sensors
6. Polymer nanoparticle sensors
   6.1. Microgels
   6.2. Polymers and Grafts
6.3 Microgel/Metal Nanostructures
7. Semiconductor nanoparticle sensors
8. Conclusion and Outlook

Glossary
Acknowledgement
Bibliography
Biographical Sketch

Summary

Nanotechnology is the engineering and art of manipulating matter at the nanoscale. Nanoscaled inorganic composite materials have been used due to their high chemical inertness, non-swelling effect, high purity and rigidity. The versatility of physical and chemical properties of metal, semiconductor, noble and composite nanoparticles render them as promising materials in the fields ranging from optoelectronics to sensors. These nanoparticles or their self-assembles are able to discriminate the mixtures of gases,
volatile organic compounds, and odors. Advances in the fabrication of metal and noble metal nanoparticles have yielded nanostructured materials with distinctive properties, which can be potentially applied to (bio)sensors. The integration of metallic or semiconductive nanoparticles with organics and biomaterials (e.g., dyes, enzymes, nucleic acids, or antigens/antibodies) has led to the development of electrochemical or optical biosensors. Hybrid nanoscale materials are well established in various processes such as organic and inorganic compounds, nucleic acid detachment, protein separation, and immobilization of enzymes. Those nanostructures can be used as the building blocks for electronics and sensor devices because uniform metal coatings with the small and monodisperse domain sizes are crucial to optimize nanoparticle conductivity and to detect changes in conductivity and absorption induced by analyte adsorption on metal nanoparticle surfaces. The highly ordered assembly of zero-dimensional and one-dimensional nanoparticles is not only necessary for making functional devices, but also presents an opportunity to develop novel collective properties. Nanoscale semiconducting materials such as carbon nanotubes or nanowires show great potential for use as highly sensitive electronic sensors. In order to meet the specific requirements demanded by particular applications, the chemical modification of carbon nanotubes is essential. The derivatized carbon nanotubes differ from the crude material in their good solubility, which enables both a more extensive characterization and subsequent chemical reactivity. Quasi-one-dimensional semiconducting nanostructures, such as nanowires or nanobelts, are considered as an important multifunctional building block for fabricating various nanosensors and nanodevices. The field effect transistor is not only a basic electronic device but also exhibits a broad range of sensor applications. Semiconductor nanocrystals known as quantum dots have been increasingly utilized as biological imaging and labeling probes because of their unique optical properties, including broad absorption with narrow photoluminescence spectra, high quantum yield, low photobleaching, and resistance to chemical degradation. The surface modification of quantum dots with antibodies, aptamers, peptides, or small molecules that bind to antigens present on the target cells or tissues has resulted in the development of sensitive and specific targeted imaging and diagnostic modalities for in vitro and in vivo applications. Noble metal nanoparticles, with desirable nanoscaled sizes and unique physical properties - particularly the colors associated with their surface plasmon resonance- are highly suitable signal transducers for biosensors and building blocks in nanoassemblies. In particular, surface-enhanced Raman scattering nanosensors enable the chemical characterization of the nanometer vicinity of the gold nanoparticles and the measurement of vibrational spectra at a sensitivity and lateral resolution unachieved so far in other experiments. Micro- and nanofabricated cantilevers can provide a versatile platform for real-time, in situ measurements of physical, chemical, and biochemical properties of physiological fluids. New stimuli responsive properties were developed in N-isopropylacrylamide monomer and its derivatives around the critical temperature, above which its polymer precipitates out of solution or changes its volume, making it a valuable material for applications in sensing, analysis and microfluidics.

1. Introduction

In the last decade, the application of nanometer materials has received increasingly great attention in the field of nanotechnology, biotechnology and bioanalytical
chemistry. Nanotechnology is the engineering and art of manipulating matter at the nanoscale (1–100 nm). For environmental applications, nanotechnology offers the potential of novel functional materials, processes and devices with unique activity toward some contaminants, enhanced mobility in environmental media and desired application flexibility. Many nano-based environmental technologies (e.g., sensors, sorbents, and reactants) are under very active research and development, and are expected to emerge as the next generation environmental technologies to improve or replace various conventional environmental technologies in the near future.

Many fields of nanotechnology are based on physical and chemical interactions, involving nanoparticles of particular size and shape. Nanoparticles (NPs) played an important role in absorption/adsorption of (volatile) organic molecules and gases due to their large specific surface area and high surface energy. Nanoscaled inorganic materials have received much more attention because of their high chemical inertness, non-swelling effect, high purity and rigidity. In order to use the nanomaterials as sensors, one has to understand the peculiarities of both the synthesis and interaction mechanism during the sensing act. In recent years, the interest of researchers and engineers to gas- and liquid-sensitive materials has grown substantially due to the progress in nanotechnology. This interest is primarily connected to the promising electronic properties of nanomaterials, their size dependence, and the possibility of controlling the material structure by using new experimental techniques.

New generations of low power, low cost, and portable sensing devices are needed for monitoring of agriculture, chemistry, physics, medical, and manufacturing environments. With the recent developments in nanoscience and nanotechnology, there is a pressing need for flexible, mechanically robust, and environmentally stable chemical vapor sensors with a high efficiency and low power consumption. Among the main trends in the particle-gas-sensor nanotechnology, the creation of sensor arrays or “electronic noses” should be mentioned. Such multisensor systems can be fabricated on a single substrate, which can involve gas sensors of different types and, necessarily, the signal-processing systems. There are many examples of successive production of their nanostructured prototypes, which are able to discriminate the mixtures of gases, volatile organic compounds, and odors.

In recent years, tremendous attention has been paid to inorganic nanosize crystals because of their significant properties determined by the high surface areas and quantization of most electronic properties. Nanometer-sized inorganic particles potentially have unique properties because of quantum confinement effects and their large surface area relative to their volume. The versatility of physical and chemical properties of metal and semiconductor nanoparticles render them as promising materials in the fields ranging from optoelectronics, sensors to medicine. Thus far, great research interests have been involved in fabricating nanoparticle assemblies because they represent a popular route toward the preparation of advanced functional materials as well as a central concept in nanoscience and nanotechnology.

Recent advances in the fabrication of noble metal nanoparticles have yielded nanostructured materials with distinctive properties, which can be potentially applied to (bio)sensors, nonlinear optics, catalysis, telecommunications, and other fields. For
example, the functionalized gold particles have shown $10^4$ to over $10^7$ times signal enhancements on Raman spectroscopy (surface enhanced Raman scattering, SERS), more than 1000-fold enhancements on surface plasmon resonance (SPR) spectroscopy compared with nonparticle binding events, improvements of colorimetric sensing of DNA and other applications. These enhancements result from the particles’ collective properties, which are dependent on the particle’s dielectric function (optical properties of a single particle), the volume fraction of particles, and their spatial distribution. For metallic nanoparticles that are small compared to the wavelength $\lambda$ of an incident light, the dielectric function is known to be size-dependent, i.e., different from bulk values.

Significant challenges exist in assembling and interconnecting the building blocks of a nanoscale device and being able to electronically address or measure responses at the molecular level. Self-assembly is one of the few practical strategies or making ensembles of nanostructures and will therefore be an essential part of nanotechnology. In order to generate complex structures through self-assembly, it is essential to develop methods by which different components in solution can come together in an ordered fashion.

The preparation of novel magnetic nanocomposites or nanocrystals (NCs)/nanoparticles of improved properties are another important aspect in nanotechnology- and nanomaterials-related applications. Magnetically driven separations of small biological components and cells, detoxification of undesirable molecules and antigens, magnetic field-guided delivery of drugs and genes, relaxation and contrast enhancement in noninvasive magnetic resonance imaging (MRI) of tissues, piezoelectric immunosensors, and magnetic fluid hyperthermia for cancer therapy have been recently disclosed in those areas.

An advantage to applying biological recognitions to synthesize metal nanocrystals or nanoparticles is the efficient and reproducible nanocrystal production in the control of size and packing density without contaminating with precipitated metal aggregates. This is important when those nanoparticles are practically used as the building blocks for electronics and sensor devices because uniform metal coatings with the small and monodisperse domain sizes are crucial to optimize nanoparticle conductivity and to detect changes in conductivity and absorption induced by analyte adsorption on metal nanoparticle surfaces.

Within the general activities of nanotechnology, the use of biomaterial-nanoparticle hybrid systems for biosensor, bioelectronic, and circuitry applications has substantially advanced, and these efforts have established the rapidly developing field of nanobioelectronics and nanobiotechnology. For example, the integration of metallic nanoparticles with biomaterials (e.g. enzymes, nucleic acids, or antigens/antibodies) has led to the development of electrochemical or optical biosensors. Similarly, the integration of biomaterials with semiconductor nanoparticles has led to the development of optical or photovoltaic biosensor systems. Also, nanoparticles have been incorporated into biomaterials that act as templates, and the resulting structures have been grown into metallic or semiconductor nanocircuitry. This latter approach was suggested as a bottom-up miniaturization method for fabricating nanostructures with dimensions that are smaller than the presently achievable patterns using lithography.
The application of methodologies to produce nanoparticles with bioresponsive properties has opened the way for producing useful tools for molecular diagnostics, therapeutics, and biotechnology. Hybrid nanoscale materials are well established in various bioprocesses such as nucleic acid detachment, protein separation, and immobilization of enzymes. An important area of interest is the immobilization of proteins and enzymes on magnetic particles.

The reliance of future technologies on exploring facile and economic methods for the fabrication of one-dimensional (1D) systems has spurred intense and rapid development in the field of material synthesis. In particular, metal and semiconductor nanorods, as a family of 1D nanostructures, have been extensively pursued for their potential in building blocks for self-assembled nanoscale electronic circuits, sensors and energy-conversion devices. The highly ordered assembly of such nanorods (NRs) is not only necessary for making functional devices, but also presents an opportunity to develop novel collective properties.

Nanoscale semiconducting materials such as carbon nanotubes (CNTs) or nanowires show great potential for use as highly sensitive electronic sensors. Single-walled carbon nanotubes (SWCNTs) arguably are the ultimate biosensor in this class for a number of reasons: SWCNTs have the smallest diameter (~ 1 nm), directly comparable to the size of single biomolecules and to the electrostatic screening length in physiological solutions. Covalent coupling of organic materials to CNTs is highly important. In order to meet the specific requirements demanded by particular applications (for example nanotube-based sensors or nanodevices), the chemical modification of CNTs is essential. Through the chemical functionalization of SWCNTs, the prerequisites for possible applications of such nanostructures have been established. The derivatized CNTs differ from the crude material in their good solubility, which enables both a more extensive characterization and subsequent chemical reactivity. Various defects in the carbon nanotube structure provide sites for their covalent derivatization.

Important chemical means to functionalize CNTs to yield systems of tailored solubility and structural features are desired. Nonetheless, the integration of CNTs with other electronic materials, such as conductive polymers or nanoparticles, is anticipated to generate materials of new properties and functions. The use of biomolecules as templates for fabricating metal contacts may be a major advance. With these advances in the area of the organic or biomolecule-CNT hybrid systems, one may look forward to exciting new applications.

Nanowire-based field-effect transistors (FET) have been widely used for detection of a variety of biological and chemical species, detection of pH value, detection of metal ions, viruses, proteins, etc. In most of these applications, the mechanism of sensing is based on the functionalization of a homogeneous semiconducting nanowire, such as silicon and In_2O_3 nanowires. The extreme sensitivity of nanowire (NW) and nanotube (NT) field-effect sensors originates from their one-dimensional structure that enables efficient charge transfer between the surface-anchored biomolecules and NW/NT. However, they are also highly sensitive to impurities and other ionic species in analyte solution, especially at the acclaimed low DNA concentration.
Quasi-one-dimensional semiconducting nanostructures, such as nanowires (NWs) and nanobelts (NBs), are considered as an important multifunctional building block for fabricating various nanodevices. Owing to their unique electronic, optical, and piezoelectric properties, for example, ZnO NWs/NBs have been successfully applied in field effect transistors, sensors, and piezoelectric devices. The field effect transistor is one of the most studied systems since it not only is a basic electronic device but also exhibits a broad range of sensor applications. The mechanism of nanowire sensors for sensing gases, biomolecules, or even virus relies on the creation of a charge depletion zone in the semiconductor nanowire by the surface adsorbed sensing targets.

Semiconductor nanocrystals known as quantum dots (QDs) have been increasingly utilized as biological imaging and labeling probes because of their unique optical properties, including broad absorption with narrow photoluminescence spectra, high quantum yield, low photobleaching, and resistance to chemical degradation. In some cases, these unique properties have conferred advantages over traditional fluorophores such as organic dyes. The surface modification of quantum dots with antibodies, aptamers, peptides, or small molecules that bind to antigens present on the target cells or tissues has resulted in the development of sensitive and specific targeted imaging and diagnostic modalities for in vitro and in vivo applications. Quantum dots, fluorescent colloidal semiconductor nanoparticles, have been developed to provide materials compatible in size with biomolecules for use as fluorescent biosensors as they are reasonably resistant to photobleaching, to denaturants of biomolecules, and to alterations in pH and temperature.

Gold nanoparticles, with desirable nanoscaled sizes and unique physical properties (particularly the colors associated with their surface plasmon resonance (SPR)), are highly suitable as signal transducers for biosensors and building blocks in nanoassemblies. In particular, surface enhanced Raman scattering (SERS) nanosensors enable the chemical characterization of the nanometer vicinity of the gold nanoparticles and the measurement of vibrational spectra at a sensitivity and lateral resolution unachieved so far in other experiments. There is compelling evidence that high SERS enhancement levels are associated mainly with enhanced local optical fields. This implies that the SERS enhancement factor depends strongly on the morphology (e.g., the size, shape, or aggregation) of the nanoparticles. Composite nanoparticles with gold nanoshells are fascinating nanoparticles composed of a spherical dielectric core coated with a nanometer thin gold layer. Their scattering spectra show a pronounced resonance in the visible range, similar to solid noble-metal nanospheres. The origin of this resonance behavior is a collective oscillation of the conduction band electrons, which is known as the nanoparticle plasmon (NPP).

The polymerization of N-isopropylacrylamide (NIPAM) have been explored because poly(NIPAM) (PNIPAM) is well-known for its characteristic lower critical solution temperature (LCST) in water at 32 °C, above which it precipitates out of solution, makes it a valuable material for applications in bioanalysis and microfluidics. The same property was of interest to us also to quickly assess whether polymer chains were formed by raising the temperature above the LCST. New stimuli responsive properties of PNIPAM are based on the precipitation of polymer out of solution or changes to its
volume, making it a valuable material for applications in sensing, analysis and microfluidics.

In some specific applications, it would be highly desirable to modulate the spatial distribution between nanoparticles arising from the change in polymer chain conformations in response to some external chemical or biochemical species. For example, the nanosensors based on the CdSe nanoparticles immobilized on pH-responsive poly(2-vinyl pyridine) (P2VP) brushes were studied. It has been realized that stimuli-responsive variation in the thickness of polymer brushes leads to the change in optical properties of immobilized nanoparticles and hence opens the new avenue for fabrication of nanosensors. Owing to the multifunctional properties of silver nanoparticle and responsiveness of P2VP brushes with the pH of surrounding media, the obtained P2VP-silver nanoassemblies can be used as pH nanosensors.

Conjugated polymers are emerging materials for biological sensor applications because of their signal amplification property and environmental sensitivity. Moreover, controlled assembly of fluorescent sensory polymers expands the dimensionality of the energy transport properties from one-dimensional (1D) to two-dimensional (2D) and to three-dimensional (3D) efficiently, augmenting the intrinsic high sensitivity even further. For example, conjugated polymers based on phenyleneethynylene, polycetylene, orinorganicpolymetalloles are efficient optical sensors for nitroaromatics.

Design and fabrication of chemical sensors has become one of the most active research fields due to their diverse practical and potential applications. To improve the sensing characteristics, a general route is to make chemical sensors at the nanoscale, taking advantage of the large surface areas of nanoscale structures. Chemical nanosensors based on one dimensional carbon, silicon, and ceramic nanostructures are of particular interest because of their high surface to volume ratio and special physical and chemical properties. A chemical sensor based on the simple change in resistance in response to the binding of analytes. Advantages of chemiresistors include low power consumption and the ease of high precision resistance measurements. Several materials have been utilized as gas sensors, including metal oxides, organic semiconductors, and carbon nanotubes. Metal oxides are the most widely used materials for chemiresistors. Despite their sensitivity, the applications of these materials have been limited by high power consumption and poor selectivity. Organic semiconductors, especially conjugated polymers, have long been considered as chemiresistor materials. The integration of molecular recognition into their structures is attractive; however, these materials are limited by electrostatic/dielectric interferences and fragile organic metal interfaces. Among the chemical nanosensors, the humidity nanosensor is very important for their practical applications in environment monitoring, industrial process control, and our daily life. Many humidity nanosensors based on 1D nanostructure have been successfully obtained. However, the sensing characteristics (e.g., response, recovery, reproducibility, stability, and linearity) still need to be improved.

Electrochemical sensors provide unlimited opportunities for monitoring environments and making the world safer and cleaner. Such devices meet the environmental and security demands for monitoring electroactive pollutants or threat agents with high
sensitivity, selectivity, and temporal resolution. Electrochemical detection is of particular significance in the development of aptasensors since it allows for high sensitivity and selectivity, simple instrumentation, as well as low endogenetic background. Many electrochemical strategies only incorporate the aptamer-target binding events into the sensor design, and the presence of target is signaled either via direct measurements of electrochemical parameters such as impedance and potential or through indirect detection of certain exogenous labels including enzymes and nanoparticles. Another conceptually distinct mechanism for electrochemical aptasensors is based on conformational changes induced by strand displacement or structure switching.

Microcantilevers are nanomechanical transducers, which convert intermolecular reaction forces to detectable cantilever deflection in nanometers. When specific reactions among (bio)molecules occur on one surface of a cantilever, the reactions induce a change in the surface stress as a result of the free energy reduction. The cantilever deflects due to the change of surface stress and indicates the occurrence of the specific chemical and biomolecular reaction. To achieve sensitive and repeatable performance of microcantilever sensors for the detection of intermolecule interactions, one can explore different surface chemistries for passivation of inactive surfaces and several different surface chemistries for functionalization of active surfaces with probe molecules (antibodies).

The terms “actuator”, “sensor”, and “transducer” are used in the description of measurement systems—sometimes interchangeably. In the broadest sense, a transducer receives energy from one system and transmits this energy to another system, often in a different form. A sensor monitors a system; it responds to physical stimuli, such as heat, light, pressure, or motion, and generates an electronic impulse for detection. An actuator, on the other hand, imposes a state upon a system. Most commonly, this involves converting an input electrical impulse into motion. Thus, actuators and sensors are both transducers intended for different tasks. In accord with these general definitions, an electromechanical transducer converts electrical energy into mechanical energy, and vice versa.

In this chapter, we focus on summarization and discussion of literature data on the most central concern in sensor and nanotechnology: preparation, properties and functioning of sensor at the nanoscale range shortly above mentioned.

2. Metal Nanoparticle Sensors

Nanoparticles are nanometer-size materials with unique physical and chemical properties and have been widely used for many years. Organic molecules, also in the nanometer-size range, possess functionalities that enable recognition and self-assembly. The combination of nanoparticles and chemical or biological molecules is very attractive and has gained tremendous attention from academics and industry, because such a combination could create new materials for electronics and optics and lead to new applications in genomics, proteomics, and biomedical and bioanalytical areas. For environmental applications, nanometer-size particles and their self-assemblies offer the potential of novel functional materials, processes and devices with unique recognition
activities, enhanced mobility in environmental media and desired application flexibility. Many nano-based environmental technologies (e.g., sensors,..) are under very active research and development, and are expected to emerge as the next generation environmental technologies to improve or replace various conventional environmental technologies in the near future.

The preparation of nanomaterials is one of the most active fields in material science. A number of techniques have been used for the production of nanoparticles: gas-evaporation, sputtering, sol-gel method, hydrothermal, microemulsion, polyols, laser pyrolysis, sonochemical synthesis, chemical coprecipitation, and so on. Among them, the surfactant assembly mediated synthesis is attracting more attention because it allows for a good control of the synthesis process at ambient reaction condition. Experimental parameters such as pH, reactant concentrations, stirring speed, titration rate, reaction time and external temperature can, to some extent, influence the composition and surface properties of produced metal nanoparticles and hence need to be maintained constant in the experiments to produce consistent samples. Other methods based on a modified sol–gel technique as well as on the original approach that uses the mechanochemical milling, were also employed for improving the sensor performance of nanostructured metal and metal-oxide materials. Besides enhancing the characteristics of existing gas- and liquid- sensitive elements, nanotechnology also promotes the development of new types of composite nanomaterials for microelectronics and sensorics.

New prospects in designing nanosensors based on nanoparticles were opened by the synthesis of new metal and noble metal nanoparticles. It was shown that pore-free crystals of some nanocrystals can reversibly take up and evolve gas without breaking the crystal, that is, the nanocrystals can breathe. For example, when interacting with gas (sulfur dioxide, chlorine, carbon dioxide,..), a crystal changes the color. The change in its color can be attributed to the transition of square-planar complexes of nanoparticles into square pyramidal complexes of nanoparticles with liquid or gas, for instance, as the fifth ligand. In doing so, the crystal increases in volume, while retaining the ordered lattice structure. Yet a more interesting result is obtained if a crystal with increased volume is exposed to air. In this case, the crystal “breathes out” gas and relaxes to its original, colorless, and gas-free state. This process can be repeated many times without breaking the crystal.

In comparison with polymer matrices and biomembrane-like films inorganic materials are thermally stable and chemically inert in aqueous and nonaqueous solutions. Many inorganic materials, such as clays, sol–gels, nanoparticles and carbon nanotubes have been proven to be the promising matrices to construct (bio)sensors. Mesoporous materials have attracted attention these years in protein immobilization because of their unidirectional pore topologies and large surface areas. However, the pore of mesoporous materials is rigid, so the uptake of guest species is limited by the minimal channel cross-section.
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Hahm J. and Lieber C. (2004). Direct Ultrasensitive Electrical Detection of DNA and DNA Sequence Variations Using Nanowire Nanosensors. *Nano Letters* 4, 51-54. [A document that provides information on detection of biomolecules and how they are highly sensitive to impurities and other ionic species in analyte solution, especially at the acclaimed low DNA concentration].


Hammond P.T. (2004). Form and function in multilayer assembly: New applications at the nanoscale. *Advanced Materials* 16, 1271. [This study reports on great research interests which have been involved in fabricating nanoparticle assemblies because they represent a popular route toward the preparation of advanced functional materials as well as a central concept in nanoscience and nanotechnology].

erosion of the genetic information in the chromosomes through the labile self-destruction and shortening].


He P. and Dai L. (2004). Aligned carbon nanotube–DNA electrochemical sensors. *Chemical Communication* 348-349. [The comprehensive investigation on the aligned nanotube structures and various transduction materials to effectively enhance the sensitivity and to broaden the scope of analytes to be detected].


Hirsch A. (2002). Funktionalisierung von einwandigen Kohlenstoffnanoröhren. *Angewandte Chemie* 114, 1933 -1939. [A document describes the derivatization, extensive characterization and subsequent chemical reactivity ofCNTs where various defects in the carbon nanotube structure provide sites for their covalent derivatization].

Ho H.A. and Leclerc M. (2004). Optical sensors based on hybrid aptamer/conjugated polymer complexes. *Journal of the American Chemical Society* 126, 1384-1387. [This contribution describes the specific interaction between thrombin and its binding aptamer and the colorimetric detection of the aptamer-thrombin interactions].

Hoare T. and Pelton R. (2005). Electrophoresis of Functionalized Microgels: Morphological Insights. *Polymer* 46, 1139-50. [An investigation on the “smart” microgels that can be tuned specifically in order to generate fast and targeted swelling responses to multiple external stimuli, such as both temperature and pH].

Homs W.C.I. (2002). DNA sensors. *Analytical Letters* 35, 1875. [A comprehensive study on a major feature of the Watson-Crick model of DNA that provides a vision of how a base sequence of one strand of the double helix can precisely determine the base sequence of the partner strand for passing the genetic information in all living species].

Polymers for Switching of Surface Charge and Composition in Aqueous Environment. *Macromolecules* **36**, 5897-5901. [This is a study reporting on highly responsive pH dependent reversible swelling for polymer brushes, prepared from weak polyelectrolytes].


Jakobson C., Bloom I. and Nemirovsky Y. (1998). Noise in CMOS transistors for analog applications from subthreshold to saturation. *Solid-State Electronics* 42, 1807–1817. [It was reported that silicon dioxide is an unsuitable material as a gate-dielectric for biochemical field-effect transducers (ISFETs), as it is unstable in electrolytic solutions and the surface of the silicon dioxide is responsible for the high noise level in silicon-based electrolyte silicon dioxide field-effect transistors].


Ji H.-F, Thundat T., Dabestani R., Brown G.M., Britt R.F. and Bonnesen R.V. (2001). Ultrasensitive detection of CrO$_4^{2-}$ using a microcantilever sensor. *Analytical Chemistry* 73, 1572. [This research provides information on the surface stresses that lead to mechanical bending of cantilevers].

Jin R., Wu G., Li Z., Mirkin C.A. and Schatz G.C. (2003). What controls the melting properties of DNA-linked gold nanoparticle assemblies? *Journal of the American Chemical Society* 125, 1643-1653. [This study examines the ratio metric method that allows simple and fast quantification with minimal effects from sampling conditions and the melting temperature of nanoparticle aggregates].


Kamin R.A. and Wilson G.S. (1980). Rotating ringdisk enzyme electrode for biocatalysis kinetic studies and characterization of the immobilized enzyme layer. *Analytical Chemistry* 52, 1198–1205. [This document discusses the apparent Michaelis–Menten constant (K$_{\text{m}}^{\text{app}}$), which gives an indication of the enzyme–substrate kinetics for the glucose biosensor].

Kanel S., Manning B., Charlet L. and Choi H. (2005). Removal of arsenic(III) from groundwater by nano scale zero-valent iron. *Environmental Science and Technology* 39, 1291-98. [This study demonstrates that nanoscale iron particles are effective for the transformation of a wide array of common environmental contaminants such as metal ions].

Katz E. and Itamar Willner. (2004). Biomolecule-Functionalized Carbon Nanotubes: Applications in Nanobioelectronics. *Chemical physics and physical chemistry* 5, 1084 -1104. [This study reviews the use of biomolecules as templates for fabricating metal contacts in the area of the organic or biomolecule-CNT hybrid systems].

Katz E. and Itamar Willner. (2004). Biomolecule-Functionalized Carbon Nanotubes: Applications in Nanobioelectronics. *Chemical physics and physical chemistry* 5, 1084 -1104. [This study reviews the use of biomolecules as templates for fabricating metal contacts in the area of the organic or biomolecule-CNT hybrid systems].


Kneipp J., Kneipp H., Rice W.L. and Kneipp K. (2005). Optical probes for biological applications based on surface-enhanced Raman scattering from indocyanine green on gold nanoparticles. *Analytical Chemistry* 77, 2381-2385. [This is interesting study on the SERS labels in cells, using gold or silver nanoparticles and reporter molecules].

Kneipp K., Kneipp H. and Kneipp J. (2006). Surface-Enhanced Raman Scattering in Local Optical Fields of Silver and Gold Nanoaggregates From Single-Molecule Raman Spectroscopy to Ultrasensitive Probing in Live Cells. *Account of Chemical Research* 39, 443-450. [The present paper shows an evidence that high SERS enhancement levels are associated mainly with enhanced local optical fields and that the SERS enhancement factor depends strongly on the morphology (e.g., the size, shape, or aggregation) of the nanoparticles].


block- poly(acrylic acid) (PSt-b-PAA)].


Kopelman R. (1988). Fractal reaction kinetics. *Science* **241**, 1620-1626. [This study provides information on surface diffusion-controlled reactions that occur on clusters or islands and they are expected to exhibit anomalous and fractal-like kinetics].


Kulys J., Wang L. and Maksimoviene A. (1993). L-lactate oxidase electrode. based on methylene green and carbon paste. *Analytica Chimica Acta* **274**, 53–58. [This paper describes the rapid and accurate determination of hydrogen peroxide which is of great importance because it is not only the product of the reactions catalyzed by many highly selective oxidases but also an essential compound in food, pharmaceutical and environmental analyses].


Nanomechanical Resonator. *Science* **304**, 74. [182] [This studies the capacitive displacement detection - the motion of the mechanical element modulates the electrical capacitance between the element and a fixed gate].


Lavrik N.V., Sepaniak M.J. and Datskos P.G. (2004). Cantilever transducers as a platform for chemical and biological sensors. *Review of Scientific Instruments* **75**, 2229-2253. [This is a study on both static and dynamic responses of cantilever sensors measured with very high precision using several readout techniques based on optical beam deflection, interferometry, electron transfer, piezoresistance, capacitance, and piezolectric properties].


Lemieux M., Usov D., Minko S., Stamm M., Shulha H. and Tsukruk V.V. (2003). Reorganization of binary polymer brushes: Switching Surface microstructures and nanomechanical properties. *Macromolecules* **36**, 7244-7255. [This contribution discusses the influence of the charge density and changes in pH on the interior of the polymer brushes, which is then forced by electrostatic repulsions to stretch out, however, to swell to a thickness several times greater than that for the uncharged polymer].


Li J., Lu Y., Ye Q., Delzeit L. and Meyyappan M. (2005). A Gas Sensor Array Using Carbon Nanotubes and Microfabrication Technology. *Electrochemical and Solid-State Letters* **8**, 11, H100-H102. [This presents that the pristine nonaligned carbon nanotubes for gas sensing often involves tedious processes for integrating single carbon nanotube into sensor devices, and the number of analytes to be determined is also hampered by the limited specific interactions with the unmodified nanotubes].


Li Z. and Hu N. (2003). Direct electrochemistry of heme proteins in their layer-by-layer films with clay nanoparticles. *Journal of Electroanalytical Chemistry* **558**, 155–165. [A comprehensive investigation on inorganic materials, such as clays, sol–gels, nanoparticles and carbon nanotubes as the promising matrices to construct (bio)sensors].

149. [A contribution about amperometric detection of organophosphorus pesticides and nerve agents performed using a screen-printed biosensor based on co-immobilized acetylcholine esterase, choline oxidase, and CNTs]


Liu J. and Lu Y. (2003). A Colorimetric Lead Biosensor Using DNAZyme-Directed Assembly of Gold Nanoparticles. *Journal of the American Chemical Society* **125**, 6642-6643. [This investigation employed a Pb²⁺-dependent DNAzyme to assemble nanoparticles and demonstrated that the nanoparticles showed different assembly states controlled by the concentration of Pb²⁺ cations].


Liu J. and Lu Y. (2004). Accelerated Color Change of Gold Nanoparticles Assembled by DNAzymes for Simple and Fast Colorimetric Pb²⁺ Detection. *Analytical Chemistry* **76**, 1627-1632. [A comprehensive study on extending the range of analytes that can be detected by using this method beyond metal ions to analytes such as adenosine by introducing aptamers into the above DNAzyme system to form aptazymes].


Liu Y., Mills R.C., Boncella J.M. and Schanze K.S. (2001). Fluorescent Polyacetylene Thin Film Sensor for Nitroaromatics. *Langmuir* **17**, 7452-7455. [This contribution shows that some conjugated polymers such as substituted polyacetylenes can be widely investigated as fluorophores].


Lu Y. (2002). New Transition Metal-Dependent DNAzymes as Efficient. Endonucleases and as Selective Metal Biosensors. *Chemistry European Journal* **8**, 4588-4596. [This is a case study reporting on DNA catalytic functions, including DNA/RNA cleavage, ligation, phosphorylation, and porphyrin metalation].


Lu Y., Mei Y., Drechsler M. and Ballauff M. (2006). Thermosensitive core-shell particles as carrier systems for metallic nanoparticles. *Journal of Physical Chemistry B* **110**, 3930-7. [This is a work on the surface plasmon absorption band of the silver nanoparticles that shifts to higher wavelengths with temperature, which is traced back to the varying distance of the nanoparticles caused by the swelling and the shrinking of the shell].

Luzinov I., Minko S. and Tsukruk V.V. (2004). Adaptive and responsive surfaces through controlled reorganization of interfacial polymer layers. *Progress in Polymer Science* **29**, 635-698. [A comprehensive discussion on polymer chains anchored by one end to substrates which provide an entry to the fabrication of versatile adaptive surfaces capable of responding to changes of temperature, solvent polarity, pH, and other stimuli, generally by reversible swelling].


Makino K., Yamanoto S., Fujimoto K., Kawaguchi H. and Oshima H. (1994). Surface structure of latex particles covered with temperature-sensitive hydrogel layers. *Journal of Colloid and Interface Science* **166**, 251-8. [A document that reports on the two-stage synthesis of thermosensitive core@shell particles consisting of a poly(styrene) core onto which a shell of poly(N-isopropylacrylamide) (PSt@PNIPAM) has been affixed].

Malinsky M.D., Kelly K.L., Schatz G.C. and Van Duyne R.P. (2001). Chain Length Dependence and Sensing Capabilities of the Localized Surface Plasmon Resonance of Silver Nanoparticles Chemically Modified with Alkanethiol Self-Assembled Monolayers. *Journal of the American Chemical Society* **123**, 1471-1482. [A further investigation on changes of surface Plasmon resonance caused by the adsorption of molecules directly to the surface of noble-metal nanoparticles or by the specific binding of analyte molecules to nanoparticles functionalized with molecular recognition sites such as antibodies].


Mara A., Siwy Z., Trautmann C., Wan J. and Kamme F. (2004). An asymmetric polymer nanopore for single molecule detection. *Nano Letters* **4**, 497-501. [This investigation indicates that the reported sensing paradigm is similar to stochastic sensing in which it is possible to hold the transmembrane potential constant and detect analyte by a drop in the steady state ion current].

Maroto A., Balasubramanian K., Burghard M. and Kern K. (2007). Functionalized metallic carbon nanotube devices for pH sensing. *Chemical Physics and Physical Chemistry* **8**, 220-223. [This document studies the functionalized single-walled carbon nanotubes (SWCNTs) arguably as the ultimate biosensor in this class for a number of reasons: SWCNTs have the smallest diameter (~ 1 nm), directly comparable to the size of single biomolecules and to the electrostatic screening length in physiological solutions].

Mattoussi H. and Matthew Mauro J. (2000). Self-Assembly of CdSe-ZnS Quantum Dot Bioconjugates Using an Engineered Recombinant Protein. *Journal of the American Chemical Society* **122**, 12142–12150 [This is the further study on some bright and photostable fluorophores that have a broad excitation spectrum but a narrow emission at wavelengths controllable by the size and composition of a core].

attached polymer brushes of controlled structure].


Mei S.H.J., Liu Z., Brennan J.D. and Li Y. (2003). An efficient RNAcleaving DNA enzyme that synchronizes catalysis with fluorescence signaling. *Journal of the American Chemical Society* **125**, 412-420. [This studies the phenomenon of catalytic ability of DNA molecules known as DNAzymes that are highly specific toward Pb²⁺, Zn²⁺, and Co²⁺ cations].


Men Y., Kubo K., Kurihara M. and Nishihara H. (2001). Redox behavior of biferrocene dithiol and disulfide derivatives in SAMs with and without gold clusters on the gold substrate. *Journal of Physical Chemistry and Chemical Physics* **3**, 3427–3430. [The contribution on the prepartion of nanoparticles containing thiol ligands that were terminated by mixed-valence biferrocenyl groups, bringing versatile redox properties to the nanoparticles].


Mirkin C.A. and Taton T.A. (2000). Materials Chemistry: Semiconductors Meet Biology. *Nature* **405**, 626-627. [This study provides information on combination of nanoparticles and chemical or biological molecules because such a combination could create new materials for electronics and optics and lead to new applications in genomics, proteomics, and biomedical and bioanalytical areas].


important functional principle employed in chemical and biological sensing that relies on the strong dependence of the nanoparticle plasmon resonance position on the refractive index of the particles’ surroundings.

Modi A., Koratkar N., Lass E., Wei B. and Ajayan P. (2003). Miniaturized gas ionization sensors using carbon nanotubes. *Nature* **424**, 171. [A review on nano-based environmental technologies (e.g., sensors, sorbents, and reactants) which are under very active research and development, and are expected to emerge as the next generation environmental technologies to improve or replace various conventional environmental technologies in the near future].


Nath N. and Chilkoti A. (2002). Creating "smart" surfaces using stimuli responsive polymers. *Advanced Materials* **14**, 1243-1247. [This is a study on polymer brushes with triggerable phase transition behavior, such as PNIPAM, which can be exploited in devices on the nano- and microscales, with potential applications for protein affinity separations].

fields].


Ngai T., Behrens S.H. and Auweter H. (2005). Novel emulsions stabilized by pH and temperature sensitive microgels. *Chemical Communications* 3, 331-3. [This work deals with PNIPAM-based smart microgels functionalized with pH ionizable, hydrophilic and reactive carboxylic acid groups in order to generate fast and targeted swelling responses to multiple external stimuli, such as both temperature and pH].


Olsvik O., Popovic T., Skjerve E., Cudjoe K.S., Hornes E., Ugelstad J. and Uhlen M. (1994). Magnetic separation techniques in diagnostic microbiology. *Clinical Microbiology Reviews* 1 (7), 43–54. [This study provides information on magnetic beads used for the separation of DNA, proteins and even cells has and has led to many commercial applications].


Park S.J., Taton T.A. and Mirkin C.A. (2002). Array-based electrical detection of DNA with nanoparticle probes. *Science* 295, 1503-1506. [The present studies summarizes the results from biosensing of DNA was using metallic NPs as electrochemical markers, by the application of NPs as catalytic labels for the enlargement of the NPs].


Patolsky F. and Lieber Ch.M. (2005). Nanowire Nanosensors. *Materialstoday* 20–29. [This paper reviews nanoscale semiconducting materials such as carbon nanotubes (CNTs) or nanowires and shows their great potential for use as highly sensitive electronic sensors].

Patolsky F., Gill R., Weizmann Y., Mokari T., Banin U. and Willner I. (2003). Lighting-Up the Dynamics of Telomerization and DNA Replication by CdSe-ZnS Quantum Dots. *Journal of the American Chemical Society* 125, 13918–13919. [This presents the fluorescence resonance energy transfer (FRET) approach to follow DNA hybridization and to identify telomerase activity in cancer cells using CdSe/ZnS core@shell QDs as the FRET stimulating sites].


Pavlov V., Xiao Y. and Willner I. (2005). Inhibition of the acetylcholine esterase-stimulated growth of Au
nanoparticles: nanotechnology-based sensing onerve gase. *Nano Letters* **5**, 649–653. [This studies summarizes numerous enzymes used to develop biosensor systems based on the biocatalytic growth of the NPs].


Pedrak R., Ivanov Tzv., Ivanova K., Gotszalk T., Abedinov N. and Rangelow I.W. (2003). Micromachined atomic force microscopy sensor with integrated piezoresistive sensor and thermal bimorph actuator for high-speed tapping-mode atomic force microscopy phase-imaging in higher eigenmodes. *Journal of Vacuum Science and Technology B* **21**, 3102-3107. [This contribution presents two common approaches to increase the speed of the scanning system: (i) to construct the stage as small as possible and (ii) to use cantilever array for parallel operation of self-actuated piezoresistive cantilevers].


Pichot C., Duracher D., Elaissari A. and Mallet F. (2000). Immobilization of modified HIV-1-capsid p24 protein onto thermosensitive cationic core/shell particles. *American Chemical Society, Polymer Preprints, Division of Polymer Chemistry* **41**, 1026-7. [This investigation devoted to the preparation and characterization of core@shell type microgels, which contain a hydrophobic core and a hydrophilic thermosensitive shell, have become attractive for scientists since such systems may combine the properties characteristic of both the core and the shell].


self-signal amplifying DNA microarrays bioconjugated to the PPE film to form a conjugated polymer-based signal amplifying sensor film].


Ramakrishnan A. and Sadana A. (2001). A single-fractal analysis of cellular analyte-receptor binding utilizing biosensors. *Biosystems* 59, 35. [This study characterizes the reactions occurring at the micro- and nanocantilever (biosensor) surface in the presence of diffusion limitations that are inevitably present in these and other types of biosensor systems].

Rangelow I.W., Ivanov Tzv., Ivanova K., Volland B.E., Grabiec P. and Sarov Y. (2007). Piezoresistive and self-actuated 128-cantilever arrays for nanotechnology applications. *Microelectronic Engineering* 84, 1260–1264. [This is a study on fabricated piezoresistive AFM probes with integrated Si tips, which are formed at the beginning of the cantilever micro-machining process].


Reinhard B.M., Sheikholeslami S., Mastroianni A., Alivisatos A.P. and Liphardt J. (2007). Use of plasmon coupling to reveal the dynamics of DNA bending and cleavage by single EcoRV restriction enzymes. *Proceedings of the National Academy of Sciences U.S.A.* 104, 2667-2672. [The study on the preparation of gold nanoparticles with desirable nanoscaled sizes and unique physical properties (particularly the colors associated with their surface plasmon resonance (SPR)) and suitable signal transducers for biosensors].

Roy J.J., Abraham T.E., Abhijith K.S., Sujith - Kumar P.V. and Thakur M.S. (2005). Biosensor for the determination of phenols based on Cross-Linked Enzyme Crystals (CLEC) of laccase. *Biosensors and Bioelectronics* 21, 206–211. [This paper reviews efforts made to obtain a simple and effective immobilization method to retain good bioactivity, such as physical adsorption, sol–gel technique, covalent crosslinking, and immobilization in polymer films].

Ruan C., Zeng K., Varghese O. and Grimes G.A. (2004). A staphylococcal enterotoxin B magnetoeleastic immunosensor. *Biosensors and Bioelectronics* 20, 585–591. [This document provides information on the interaction of magnetic beads with a magnetic field and the ensuing visualisation of binding effects or use the beads as a separation and magnetic immobilisation platform].


Sader J.E. (2002). Surface stress induced deflections of cantilever plates with applications to the atomic force microscope: V-shaped plates. *Journal of Applied Physics* 91, 9354-9361. [A further study that provides information on the preparation on microfabricated cantilevers with read-out means that are capable of measuring 10^{-12} to 10^{-15} m displacements operates as detectors of surface stresses at extremely small mechanical forces].

document that provides information on novel amperometric glucose sensor based on the ether-linked cobalt(II) phthalocyanine–cobalt(II) tetraphenylporphyrin pentamer which indicates with high bioactivity of immobilized GOx].

Sample J.L., Beverly K.C., Chaudhari P.R., Remacle F., Heath J.R. and Levine R.D. (2002). Imaging Transport Disorder in Conducting Arrays of Metallic Quantum Dots: An Experimental and Computational Study. Advanced Materials 14, 124-128. [This deals with nanoparticles as the building blocks for electronics and sensor devices because uniform metal coatings with the small and monodisperse domain sizes are crucial to optimize nanoparticle conductivity and to detect changes in conductivity and absorption induced by analyte adsorption on metal nanoparticle surfaces].

Santos A.M., Elaissari A., Martinho J.M.G. and Pichot C. (2005). Synthesis of cationic poly(methyl methacrylate)-poly(N-isopropyl acrylamide) core-shell latexes via two-stage emulsion copolymerization. Polymer 46, 1181-8. [This presents the synthesis of monodisperse core@shell particles, which consist of a core of poly(methyl methacrylate) (PMMA) and a thermosensitive shell of poly(N-isopropylacrylamide) (PNIPAM)].

Sarov Y. and Sainov S.J. (2002). Absorption sensor based on total internal reflection diffraction grating. Journal of Optics A: Pure and Applied Optics. 4, 382. [This study deals with two techniques for fluidic optical sensing by grating light reflection spectroscopy (GLRS) and total internal reflection–diffraction grating (TIR-DG)].


Sarov Y., Capek I., Janičková S., Kostič I., Konečníková A., Matay L. and Sarova V. (2004). Properties of nano-scaled disperse media investigated by refractometric measurements. In Vacuum 76, 231-235. [This study presents an ideal technique for measurements of the effective refractive index (ERI) of turbid and scattering media].


Schmid G.J. (1998). The role of big metal clusters in nanoscience. Journal Chemical Society, Dalton Transactions 7: 1077–1082. [This work discussed palladium clusters formation behaved as compact palladium at room temperature, but demonstrates the presence of a Coulomb barrier at 4.2 K].


Schrick B., Blough J., Jones A. and Mallouk T. (2002). Hydrodechlorination of Trichloroethylene to Hydrocarbons Using Bimetallic Nickel-Iron Nanoparticles. Chemistry of Materials 14, 5140-47. [This is a further document which presents iron nanoparticle technology as one of the first generation nanoscale environmental technology].

Schweitzer C. and Sciano J.C. (2003). Selective binding and local photophysics of the fluorescent cyanine dye PicoGreen in double-stranded and single-stranded DNA. Journal of Physical Chemistry and Chemical Physics 5, 4911. [This is reports the current detection method of the conventional DNA microarray with the sensory signal which is simply proportional to the number of dye-labeled analytes recognized by the probe DNAs on the microarray].

Senesac L.R., Corbeil J.L., Lavrik N.V., Rajic S. and Datskos P.G. (2003). IR Imaging Using Uncooled Microcantilever Detectors. Ultramicroscopy 97, 451. [178] [A further study that provides information on the preparation on microfabricated cantilevers that are capable of measuring very small displacements]
with detectors of surface stresses at extremely small mechanical forces].

Shankar S.S., Rai A., Ankanwar B., Singh A., Ahmad A. and Sastry M. (2004). Biological synthesis of triangular gold nanoprisms. *Nature Materials* 3, 482–488. [This is study on how one may utilize biomolecules, to grow nanoparticles, and to employ the optical properties of the synthesized nanoparticles to follow the biocatalytic processes].


Smith C.S. (1954). Piezoresistance Effect in Germanium and Silicon. *Physical Review* 94. [This is devoted to the description of the piezoresistive effect with theoretical background].

Sim S., Brodsky A., Vahey P. and Burgess L. (2000). Nanoparticle characterization in nanoliter volumes by grating light reflection spectroscopy. *Analytical Chemistry* 72, 4428-34. [It discusses the diffraction grating (DG) with indirect sensing function].


Sohn H., Sailor M.J., Magde D. and Trogler W.C. (2003). Detection of nitroaromatic explosives based on photoluminescent polymers containing metalloles. *Journal of the American Chemical Society* 125 (13), 3821–3830. [This study describes the luminescence from metallocene polymers in the presence of trace amounts of nitroaromatic molecules and that the quenching type].

Stachowiak J.C., Yue M., Castelino K., Chakraborty A. and Majumdar A. (2006). Chemomechanics of Surface Stresses Induced by Biomolecular Reactions. *Langmuir* 22, 263-268. [208] Thus, a multiplexed platform capable of screening many possible protein markers at a time is a highly desirable solution for determining the “diagnostic profiles” of various cancers. [This is a case study reporting on DNA hybridization using two-dimensional microcantilever arrays].


NANOSCIENTIFIC AND NANOTECHNOLOGIES - Nanosensors Based On Metal And Composite Nanoparticles And Nanomaterials - Ignác Capek

potentials with arrays of AlGaN/GaN electrolyte-gate field effect transistors.


Talley C.E., Jusinski L., Hollars C.W., Lane S.M. and Huser T. (2004). Intracellular pH sensors based on surface-enhanced raman scattering. *Analytical Chemistry* **76**, 7064-7068. [This investigation demonstrated the use of SERS in cells, using gold or silver nanoparticles and reporter molecules and the SERS spectra of selected reporter molecules were shown to depend on the pH value in the environment of the metal nanostructures].


Tan C., Atas E., Müller J.G., Pinto M.R., Kleiman V.D. and Schanze K.S. (2004). Amplified quenching of a conjugated polyelectrolyte by cyanine dyes. *Journal of the American Chemical Society* **126**, 13685. [This study discusses the controlled assembly of fluorescent sensory polymers which expands the dimensionality of the energy transport properties from 1D to 2D and to 3D efficiently].


Thomas S.W., Amara J.P., Bjork R.E. and Swagger T.M. (2005). Amplifying fluorescent polymer sensors for the explosives taggant 2,3-dimethyl-2,3-dinitrobutane (DMNB). *Chemical Communications* **36**, 4572–4574. [This work is devoted to discussion of conjugated polymers based on phenyleneethynylene, polyacetylene, orinorganic polynmetallos used as optical sensors for nitroaromatics].

Tokareva I., Minko S., Fendler J.H. and Hutter E. (2004). Nanosensors Based on Responsive Polymer Brushes and Gold Nanoparticle Enhanced Transmission Surface Plasmon Resonance Spectroscopy. *Journal of the American Chemical Society* **126**, 15950-15951. [335] [This is a case study reporting on the
nanosensor of gold nanoparticle/polymer conjugates showing enhanced transmission surface plasmon resonance (T-SPR) spectroscopy.

Tsai Y.C., Li S.C. and Liao S.W. (2006). Electrodeposition of polypyrrole–multiwalled carbon nanotube–glucose oxidase nanobiocomposite film for the detection of glucose. *Biosensors and Bioelectronics* 22, 495–500. [This study indicates that carbon nanotubes are attractive materials for application to biosensors due to the low-potential detection of hydrogen peroxide and β-nicotinamide adenine dinucleotide (NADH) and the minimal surface passivation during the electrochemical oxidation of NADH].

Uemura T., Ohba M. and Kitagawa S. (2004). Size and Surface Effects of Prussian Blue Nanoparticles Protected by Organic Polymers. *Journal of Inorganic Chemistry* 43, 7339–7345. [In this work tremendous attention has been paid to inorganic nanosize crystals because of their significant properties determined by the high surface areas and quantization of most electronic properties].


Van Ryk D.I. and Venkatesan S. (1999). Real-time Kinetics of HIV-1 Rev-Rev Response Element Interactions Definition of minimal binding sites on RNA and Protein and stoichiometric analysis. *Journal of Biological Chemistry* 274, 17452-17463. [This document discusses the surface plasmon resonance (SPR) biosensor used to analyze the kinetics of interaction between analyte and a receptor].


Vermeire S., Van Assche G. and Rutgeerts P. (2004). C-reactive protein as a marker for inflammatory bowel disease. *Inflammatory Bowel Disease* 10, 661–665. [An elevated CRP level is discussed in this study as a reliable indicator for chronic inflammatory processes like inflammatory bowel disease (e.g. Crohn’s disease)].


Wang D.Y., Lai B.H.Y. and Sen D. (2002). A General Strategy for Effector-mediated Control of RNA-cleaving Ribozymes and DNA Enzymes. Journal of Molecular Biology 318, 33–43. [This reports on increased range of analytes that can be detected by using enzymes to analytes such as adenosine by introducing aptamers into the above DNAzyme system to form aptazymes].


Wang J. (2005). Nanomaterial-Based Amplified Transduction of Biomolecular Interactions. Small 1, 1036-43. [This study opens the application of methodologies to produce nanoparticles with bioresponsive properties for producing useful tools for molecular diagnostics, therapeutics, and biotechnology].


Wang J. and Musameh M. (2003). Carbon Nanotube/Teflon Composite Electrochemical Sensors and Biosensors. Analytical Chemistry 75, 2075-2079. [This study reports on the electrocatalytic oxidation of NAD(P)H [NAD(P)H = 1,4-dihydronicotinamide adenine dinucleotide (phosphate)] cofactors and the reduction/oxidation of hydrogen peroxide stimulated by CNTs based biosensors].

Wang J., Li M., Shi Z., Li N. and Gu Z. (2002). Direct electrochemistry of cytochrome c at a glassy carbon electrode modified with single-wall carbon nanotubes. Analytical Chemistry 74, 1993-97. [This is a study reporting on properly arranged nanotubes have the capability to act as a 1D channel that guides electrons towards the redox center].

Wang J., Musameh M. and Lin Y. (2003). Solubilization of Carbon Nanotubes by Nafion toward the Preparation of Amperometric Biosensors. Journal of the American Chemical Society 125, 2408–2409. [This contribution reports on the ability of CNTs to promote the electron-transfer reactions of NADH and H₂O₂ for dehydrogenase- and oxidase-based amperometric sensor].

Wang J., Hovec S.B. and Ogorevc B. (2004). Carbon nanotube-modified glassy carbon electrode for adsorptive stripping voltammetric detection of ultratrace levels of 2,4,6-trinitrotoluene. Electrochemistry Communications 6, 176-179. [This is a study reporting on electron transfer mechanism for the quenching of luminescence emissions by nitroaromatic compounds].


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**Bibliography Sketch**

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