

Functionalizing Nanowires with Catalytic Nanoparticles for Gas Sensing Applications

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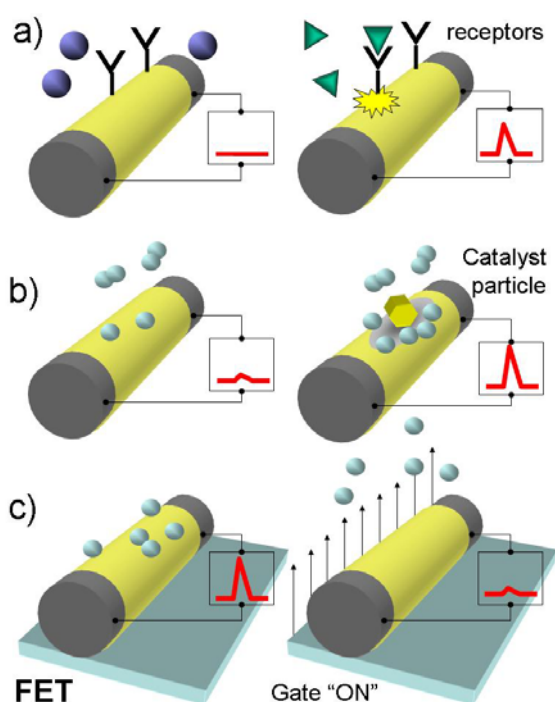


Figure 1.
Catalysis and Gas Sensing by Metal Oxide Nanowire
Systems
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Abstract- Metal oxide semiconducting nanowires are among the most promising materials systems for use as conductometric gas sensors. These systems function by converting surface chemical processes, often catalytic processes, into observable conductance variations in the nanowire. The surface properties, and hence the sensing properties of these devices can be altered dramatically, improving the sensitivity and selectivity, by the deposition of catalytic metal nanoparticles on the nanowire's surface. This leads not only to promising sensor strategies but to a route for understanding some of the fundamental science occurring on these nanoparticles and at the metal/nanowire junction. In particular, studying these systems can lead to a better understanding of the influence of the catalyst particle on the electronic structure of, and on electron transport through the nanowire. This report surveys results obtained in this area so far. In particular, the comparative sensing performance of single, quasi-1D chemiresistors (i.e. nanowires or nanobelts) before and after surface decoration with noble metal catalyst particles show significant improvement in sensitivity toward oxidizing and reducing gases. Moreover, one finds that the sensing mechanism can depend dramatically on the degree of metal coverage of the nanowire.

1. INTRODUCTION

Among its many advantages as surface-sensitive probes, quasi-1D metal oxide (MOX) nanostructures possess very large surface-to-volume ratios. Other factors which make these nanostructures particularly suitable for conductometric gas sensing include: (i) the comparability of the Debye screening length of nanostructured MOX with their lateral dimensions and (ii) the ability to fabricate them routinely with

significant lengths providing a long semiconducting channel. All these make such nanowires, nanobelts and nanorods highly sensitive and efficient transducers of surface chemical processes into electrical signals.

The feasibility of using nanowires as gas sensors was first demonstrated approximately seven years ago¹⁻⁷. Since then significant progress has been made both in terms of our fundamental understanding of the interplay between bulk and surface properties and processes in MOX nanowire sensors and their development as real world sensing platforms⁸⁻¹⁰. Despite the high sensitivity and stability already demonstrated for quasi-1D MOX sensors, a range of performance parameters, and especially their selectivity can still be improved. Some of the approaches that might be pursued in improving selectivity are illustrated in Fig.1:

(i) The surface of the nanostructure can be functionalized with a target-specific receptor species which chemically gates the conducting channel of the nanostructure when the receptor-target recognition process occurs. This is the favored strategy being pursued for bio-sensing¹¹;

(ii) The operating temperature of the sensing element can be ramped or otherwise modulated, taking advantage thereby of the fact that a target molecule normally has a characteristic optimal (or sometimes threshold) temperature above which the appropriate redox reactions occur on the sensor's surface^{12,13}.

(iii) Taking one's inspiration from the field of catalysis, one can functionalize the surface of the nanostructure with specific catalyst particles which either promote certain catalytic reactions in which the target molecules participates and/or inhibits competing reactions. But the fact that a catalytic process occurs on such particles does not necessarily translate into efficient sensing¹⁴. This is because for large conductance changes to occur, the surface chemical processes must involve significant charge transfer between the catalytic particle and the nanostructured oxide, which is not always the case. Mindful of these limitations the enhancement of the surface reactivity of CO and H₂ in oxidation reactions on Au- and Pd-catalyst-decorated SnO₂ nanowires and nanobelts have been reported with improved sensitivity and selectivity of the MOX nanowire chemiresistors towards those reactions¹⁵.

(iv) Finally, the possibility of configuring these 1D MOX nanostructures as ultra-miniature field-effect transistors (FET) offers the possibility of controlling the sensitivity and selectivity, and potentially even allowing the operating temperature of the nanowire sensor to be reduced by varying the gate electrode potential thereby changing the electrostatic field strength in the active channel with respect to some appropriate reference¹⁶⁻¹⁸.

In this brief review we describe some of the experimental progress made to date in functionalizing MOX nanostructures with metal catalysts nanoparticles.

2. EXPERIMENTAL

2.1 Individual nanowire versus ensemble of nanowires

Among the experimental opportunities (and challenges) of studying the properties of low dimensional nanostructures, and in particular the catalytic properties of MOX nanowires, is the appearance of size-dependent effects which, at the nanoscale, eventually control the electronic structure of these materials. The observed surface reactivity will, in general, depend on many parameters such as the crystal-face-dependence of the catalytic reaction rate. As a result, many of the (sometimes powerful) analytical techniques currently used to study surface chemical processes occurring at the surface of nanostructures report highly averaged results which eventually will have to be carried out with greater and greater resolution if a deep understanding of the surface chemistry occurring on these nanoscale devices is desired. An intermediate step is to carry out measurements on individual, well-characterized nanostructures. In this vein a large number of studies have been reported on the transport properties of single nanostructures configured as FETs or as resistors. Despite this progress, the detailed study of the surface chemistry occurring at the surface of individual nanostructures is still in a developmental stage¹⁹.

2.2 Model studies in vacuum

Pristine MOX nanowires synthesized using high temperature VS or VLS methods similar to those described in²⁰ are generally well faceted single-crystal systems. However, along with the opportunity that a

high surface-to-volume ratio provides is the possibility for significant surface contamination during fabrication and afterwards, sometimes by hard-to-remove polar species that alter significantly the nanowires' transport properties. When configured as a device, such as an FET, these parasitic effects might result from contamination of other locations proximate to the MOX nanostructure such as the gate oxide. These charged impurities (often hydroxyls or photoresist/solvent remnants) induce an unintentional chemical gating effect on the conducting channel which can change with time due to charge migration and/or chemical reaction. Such parasitic effects due to impurities have been observed experimentally^{8,21,22}, and often manifest themselves as transient and hysteresis effects in the I(V) or transconductance measurements. Impurity-induced gating has also been imaged¹⁹. The optimal solution would be to conduct measurements under ultra-high vacuum conditions and eliminating as much as possible wet processing during device fabrication. With these issues in mind, prior to making transport measurements it is prudent to use, whenever possible, a dry transfer to place nanowires/nanobelts on the clean oxidized side of a Si/SiO₂ (300 nm) wafer and vapor-deposit metallic (Ti (20 nm)/Au (200 nm)) source (S) and drain (D) electrodes in high vacuum onto pre-selected nanostructures using a shadow mask, so as to avoid lithography where possible. Following this procedure a single wafer with dozens of useful devices can be fabricated which can be sequentially tested in a high vacuum probe station.

Even under reasonable precautions the nanowire surface is usually contaminated with undesirable species which can block some of the reaction sites thereby inducing artifacts. Moreover, traditional cleaning methods such as rare-gas ion etching which removes surface impurities also induces structural defects²³. Likewise, annealing to high temperatures to remove defects, a technique commonly used in UHV studies of single crystal surfaces, can not normally be used with nanowire devices without destroying the contacts to the electrodes. Accordingly, UV-induced photodesorption in vacuum, or ozone exposure at moderate temperatures is normally used to clean the surface of nanowires, with variable effectiveness.

2.3 *In situ* functionalization

Because of the aforementioned sensitivity to surface impurities studies involving surface functionalization must normally conduct the functionalization *in situ* and on the same nanostructure. That is, when probing the effect of functionalization on the transport properties of nanowires, at the very least the initial experiments must be carried out on the same nanowire before and after *in situ* functionalization so as to guard against the results' being due to (impurity-induced) nanowire variability. Studies which incorporated a metal deposition source in the probe chamber for *in situ* nanowire functionalization with metal nanoparticles were recently reported with Au, Pd¹⁵, Ni²⁴ and Ag²⁵. Pd decoration produced very pronounced effects. Since the as-fabricated wafer usually contains a few individual chemiresistors or FETs on the same wafer, catalyst nanoparticle deposition was carried out through a ~100 μm circular orifice positioned over the nanostructure of interest (Fig. 2(a) top panel). Using a mask also reduced thermal radiation from the metal source. The nanowire's conductance was monitored during the deposition process by continuously measuring I_{DS} (see insert on Fig. 2 (a)). These results were correlated with subsequent HRTEM imaging of the surface deposits of metal by stopping the deposition process at various times (on various nanowires) and imaging the resulting sample (Fig.2b). In carrying out such measurements one should guard against a number of potential complications. For example, hydrogen degassing from the metal deposition source can result in a significant current transient through the MOX nanowire (see insert of Fig. 2(a)); likewise the metal deposition source must be biased positively (5-10 V) to suppress thermionic electron emission which could contribute significantly to I_{DS}.

When functionalizing the surface of single-nanostructure-based chemiresistors or FETs with metal nanoparticles, one unavoidably deposits metal on the gate oxide area between source and drain electrodes. This can affect I_{DS} as a result of electron conductance through the metal deposit after the metal nanoparticles exceed the percolation threshold. The results of measurements carried out between source and drain electrodes in the absence of a nanowire, at different temperatures and for varying metal deposition rates are shown in the Fig 3. From this we learn that:

- (i) the percolation threshold increases with increasing temperature;

(ii) at a metal deposition rate $\sim 2\text{-}3 \times 10^{-3}$ ML/s for Pd (and for this particular configuration) the current through the percolating metal deposit becomes comparable with the initial current through a pristine nanowire at $t \sim 5 \cdot 10^3$ s when the wafer was at room temperature and $t \sim 10^4$ s at 200 C and at greater times when the temperature was 270 C (curves A with B, C and D in the Fig.3). These results determine the parameters within which I_{DS} values would be characteristic of processes occurring on the individual nanowire uncompromised by those occurring in the “inter-electrode region. All gas sensing and transport measurements reported herein were carried out for metal deposition times well below those at which metal-nanoparticle percolation occurs; indeed for times well below that since electron microscopy shows that the metal deposit percolates on the surface of the nanostructure before it does on the silica substrate since the metal wets SnO_2 considerably better than it does silica.

2.4 The analysis of noble metal deposits with HRTEM and SEM

The nucleation and growth dynamics of noble metals deposited on tin oxide nanowires/nanobelts were studied by high-resolution transmission electron microscopy (HRTEM) and reported in ¹⁵. The morphological changes follow a Volmer-Weber growth mode ²⁶ with fast nucleation of high density nuclei followed by the development of 3D metal nanoparticles without further significant increase in particle density (Fig.2b). At long deposition times the particles begin to become connected and finally to percolate. The fusion into worm-like structures are likely induced by the e-beam deposition source (Fig.2b).

The availability of more advanced probe stations with SEM capabilities make *in situ* gas sensing/catalysis studies possible conjoining transport and imaging measurements. However, one needs to be mindful of complications due to electron-beam-induced effects (see for example ref ²⁷). Two related factors must be mentioned in this regard: (i) insufficient dissipation of the e-beam thermal load can result in local heating leading to MOX nanowire temperatures of hundreds K, leading, in turn, to localized reduction of the oxide and melting and coalescence of the metal nano particles decorating its surface. An example of such e-beam-induced morphological changes on a Pd-nanoparticle-decorated SnO_2 nanowire is shown in the Fig. 4. The process begins with Pd nanoparticle coalescence followed by roughening of the imaged area resulting from the beam-induced reduction of the oxide support. Metallic tin segregates to the surface and alloys with the deposited Pd. In the final stage (Fig. 4d) local melting occurs. The nanowire’s average tin/oxygen stoichiometry is at this point very different from its initial value. Clearly meaningful measurements can normally be carried out only under conditions of low beam current and short exposure times. (ii) Even when the e-beam effects do not lead to obvious morphological changes they can still influence charge transport, and therefore, the gas sensing abilities of the single-nanowire device. Even with good heat dissipation oxygen desorption can be induced by the electron beam from atomic layers near the surface ²⁸, which can lead to local n-doping of the nanowire/nanobelt that, in turn, can affect electron or hole transport (see also Fig.1 in ref. ¹⁹).

3. SURFACE FUNCTIONALIZATION OF SnO_2 NANOWIRES AND NANOBELTS WITH Pd NANOPARTICLES

3.1 Pristine nanowire surfaces

Changes in source-drain current, I_{DS} , of a single nanowire FET (or chemiresistor) were measured as a function of time at various temperatures following the introduction of sequential oxygen and hydrogen pulses with peak pressures of 0.1 and 1 mTorr, respectively. The reactant gases were introduced into the vacuum chamber using electronically pulsed solenoid valves (Fig. 5). The reactivity of the pristine SnO_2 nanowire/nanobelt surface toward an oxidizing (oxygen) or a reducing (hydrogen) gas is greatly dependent on the presence of reaction sites such as oxygen vacancies and ionically chemisorbed oxygen. That is, the reactivity of the nanowire depends critically on the effectiveness and treatment history of the nanowire. As with metal deposits, the efficiency of transduction of the surface chemical processes into a conductance change is determined by the D/r ratio. The initial conductance of a pristine SnO_2 nanostructure in vacuum at 300-600 K, is more or less proportional to the density of ionized shallow donor states resulting from oxygen vacancies (and interstitials). The fraction of the donor states which are ionized depends on the temperature.

These defects make the oxide an n-type semiconductor. The surface defects, which correspond to oxygen vacancies when the nanowire is in vacuum at elevated temperatures, become the loci for oxygen dissociation and ionization when the system is exposed to oxygen. By localizing electrons on these ionosorbed oxygens the defect states are eliminated and with their elimination the conduction electrons density is reduced. This depletes the nanowire to a depth, D and reduces the effective width of the conducting channel, thereby diminishing I_{DS} (Fig.5).

By contrast, the interaction of the pristine SnO_2 nanostructure with hydrogen results in the dissociation of the molecular hydrogen followed by electron transfer from the H (or a hydrated H) species to the conduction band of the nanowire. It is worth noting that this process, which is in principle a form of doping the nanowire, is reversible and proceeds even at low temperatures. The evolution of the conductance of a SnO_2 nanowire as a function of exposure time to 1.5×10^{-3} Torr of hydrogen in vacuum at 80 C, 200 C and 270 C are shown in Fig. 6, which shows a dramatic increase in the rate at which the process occurs with increasing temperature, indicating the activated character of the process. It seems that there are at least two processes (A and B in the Fig. 6) with “fast” and “slow” kinetics which contribute to the shape of the curves. At lower temperatures only the “slow” process is observed while at 270 C it is the “fast” process that dominates. An interesting observation is that at long exposure time the final conductance reaches the same level for all three temperatures used. The origin of these reaction channels can not be determined exclusively on the basis of conductometric measurements, but require additional spectroscopic studies.

3.2 Low Pd coverage

This regime was described in details in ¹⁵. Briefly, after characterizing the electron-transport and sensing properties of the pristine nanowire, Pd was vapor-deposited onto the same nanowire and the transport and gas sensing experiments were repeated. We ¹⁵ and others ²⁹ observed that the deposition of nanoparticles of a metal with a high work function on the surface of an n-type nanowire leads to the partial electron depletion of the conducting channel due to the local formation of Schottky barriers at the metal-nanoparticle-semiconductor interface ³⁰. These space charge regions extends 10-20 nm into the semiconductor for moderately doped oxides as recently imaged with STM for a TiO_2 (110) rutile surface ³¹ where the single-charged impurities created depleted regions a few nanometers wide. These charge depletion regions are not accessible to the conduction band electrons leading to a current drop during metal deposition (Fig.7). The extent of charge depletion depends on the work functions of the metal and semiconductor and the D / r ratio. As the metal particles nucleate and grow, I_{DS} eventually plateaus to a saturation value when neighboring depletion regions begin to overlap (middle part of the Fig.7). For a small-diameter nanowire or a narrow nanobelt these depleted regions overlap, ultimately encompassing the entire volume of the nanostructure. When this happens the conduction is no longer determined by shallow donor levels and an increase of the activation energy for conductance is observed.

In spite of the fact that a portion of the active surface of the nanostructure is occupied by the catalyst nanoparticles, the chemical reactivity (and therefore the sensitivity) of the MOX nanowire increases dramatically due to the beneficial catalytic action of the metal particles.

Typical conductance responses of an individual SnO_2 nanostructure towards sequential oxygen and hydrogen pulses as a function of Pd coverage are shown in Fig. 8a. Functionalizing the nanowire surface with Pd leads to a gradual enhancement in I_{DS} response (ΔG) for both gases at all the temperatures used in the experiment (at least up to 3000 s of metal deposition). In addition, the response time improved indicating that the metal catalyst nanoparticles directly influence the kinetics of the surface process. At all Pd coverages, raising the temperature increased I_{DS} and shortened the response time of the sensor both towards O_2 and H_2 . This effect is most prominent for hydrogen and becomes noticeable for oxygen above 543 K.

The improved overall sensing ability of the nanostructure following functionalization with Pd can be understood in terms of existing models developed for metal oxide thin film sensors ³²⁻³⁶.

Usually one calls upon two concepts in order to explain the improved nanowire sensing when it is decorated with Pd. The first states that charge depletion regions are created around the metal particles (Fig. 7 and 8b) and ascribes the improved sensing to the variation in the dimensions of the nano-Schottky barriers

(and hence the width of the conduction channel) accompanying changes in the oxidation state of the Pd (and therefore its work function) resulting from oxygen/hydrogen adsorption/desorption cycles. Indeed, the observed conduction changes during Pd deposition (Fig. 7) indicate that the nanostructure's surface electronic properties have been altered. However, the chemical effect observed is far too great even at a low level of Pd doping. Likewise, the change in kinetics of describing the adsorption/desorption cycles, and the temperature dependence induced by Pd functionalization cannot be explained solely by the Schottky mechanism. It is clear that either an alternative or an additional, chemical process takes place. This is almost certainly the catalytic dissociation of molecular oxygen/hydrogen on the Pd particles, whose atomic reaction products then diffuse over the metal oxide support. This process greatly increases both the quantity of active oxygen/hydrogen species that can repopulate (or, in case of hydrogen, create) vacancies on the SnO₂ surface and the rate at which this repopulation occurs, resulting in a greater and a more rapid degree of electron withdrawal/donation from/to the SnO₂, and at a lower temperature than for the pristine metal oxide nanowire. This mechanism, known as the "spillover effect", (Fig. 8b) is frequently alluded to in the catalysis literature^{37,38}. The size of the spillover zone for oxygen was experimentally determined around Pd nanoparticles on a TiO₂(110) surface using variable-temperature STM³⁹ and reported to be ~10 nm to several tenths of nanometers in diameter depending on particle size and experimental conditions. This implies that at particle coverages of ~10¹² cm⁻² the spillover zones overlap, thereby effectively covering the entire nanostructure surface continuously, leading to the observed saturation in chemical reactivity of the functionalized nanowires beyond a certain Pd particle density. This was very clearly seen for H₂ below 3000 s of Pd deposition (Fig. 8a). We note in passing, that for H₂ or O₂ dissociation to occur it is not necessary (or even likely) for the molecules to impinge from the gas phase directly upon the Pd nanoparticle's surface. Boudart et al.⁴⁰ and others^{41,42} showed that the molecules can first adsorb onto the oxide support and diffuse to a catalyst particle. This means that, the effective capture radius of a Pd nanoparticle can be much greater than the nanoparticle's physical radius. As with the "spillover" zones, the molecule-collection-zones⁴⁰ overlap when the Pd coverage exceeds some threshold value, effectively converting the entire surface of the nanostructure into a molecular delivery system for the Pd nanoparticles. This so-called "back-spillover effect", further increases the likelihood of molecular dissociation and ionosorption on the SnO₂ nanowire surface. As a result of these two processes, conductance changes in the nanowires covered with catalytically-active nanoparticles are often far greater for a given partial pressure of analyte gases in the ambient than in pristine nanowires.

3.3 High Pd coverage

At higher deposition times, the dependence of ΔG on Pd dose increases sharply. Specifically, for deposition times exceeding 3500 s (Fig.8a) responses to both hydrogen and oxygen increase significantly. Further increase in the Pd coverage still improves the nanowire's response to hydrogen. But, a single exposure to oxygen renders the sensor insensitive to subsequent oxygen exposure. This can be understood in greater detail by referring to Fig. 9.

Comparing the current responses to oxygen pulses for varying Pd coverage (Fig. 9a) indicates that: (i) at low coverage the magnitude and rate of response to oxygen improve with Pd concentration and is reversible, i.e. the conductance recovers upon removing the oxygen gas. (ii) At high Pd dose the conductance kinetics show a more complicated behavior; namely, a new linear conductance decay region is observed (see shaded area A in the Fig. 9a). (iii) Finally, the conductance of the sensor does not recover after a single exposure to oxygen implying that the sensing element becomes "poisoned"; (iv) but the conductance recovers fully following exposure to hydrogen pulses for all Pd doses. However, as with oxygen, a new set of kinetics appears (see shaded area B in the Fig. 9).

The observed changes in sensing properties as a function of Pd coverage can be related to metal percolation occurring on the nanowire's surface. At higher Pd coverage the percolating particles form an electrically continuous nanostructured film. In this "oxide core-metal shell" resistor the conductance and chemical effects are dominated by processes in the metal layer rather than in the semiconductor support. Under oxygen exposure the Pd particles' surface becomes oxidized. Oxidation of the percolating Pd nanoparticles results in two effects: (i) the electronic junction between percolating particles suddenly switches

from metallic to semiconducting and (ii) the entire deposited layer becomes a p-type semiconductor. In both cases conductance through the nanowire chemiresistor decreases and the kinetics no longer resemble what is observed at low Pd coverage. The irreversibility of the sensor's response to oxygen is due to the thermal stability of PdO which does not decompose below ~ 700 K⁴³. The exposure of this film to hydrogen leads to the reduction of the PdO, restoring the metallic state of the deposit and therefore its conductance. The observed anomaly in the conductance kinetics during exposure of the percolating film to hydrogen is ascribed to a process of dilation of the palladium nanoparticles during hydrogen absorption. In analogy to the sensing mechanism proposed in⁴⁴ the hydrogen adsorption-desorption cycles turn the percolation of the Pd nanoparticles on and off as a result of the cyclical increase and decrease of the volume of the Pd particles, respectively, in the presence and absence of hydrogen. This is not an instantaneous process, however, hence the observed kinetics. An alternative mechanism is associated with the diffusion of the hydrogen dissolved in the Pd nanoparticles to the Pd/SnO₂ interface changing the electronic properties of the interface region of the tin oxide nanowire. In both cases the kinetics will differ significantly from what they were for low Pd coverage.

5. CONCLUSIONS

HRTEM and STEM studies have shown that the deposition of metals such as Pd, Au, Ni, Ag on metal oxide nanowires results in nanoparticles that form according to Volmer-Weber growth. Upon deposition, electron exchange takes place between the metal particles and MOX nanowire forming nano-Schottky barriers in the vicinity of the metal particles thereby influencing electron/hole transport through the nanowire. These catalyst particles strongly influence the nanowire's conductance response towards oxidizing and reducing gases. Depending on the specific chemistry of the nanoparticle and the target gas(es), at least two major mechanisms can be invoked to explain the observed enhancement in the chemical reactivity and/or sensitivity of the nanowires: (i) the modification of the Schottky barriers between nanoparticle and oxide nanowire resulting from surface chemical reactions occurring on the nanoparticle surface, and (ii) a purely chemical catalytic effect by the nanoparticle.

Reactions on Ni and Ag nanoparticles provide examples of the first mechanism. On Ni, reduction-oxidation cycles induced by exposure to hydrogen entrained in an oxygen background affects the formation of the p-n nanojunction between the p-type NiO nanoparticle and the n-type SnO₂ nanowire. With Ag nanoparticles, ethylene oxidation on the surface of the Ag nanoparticle modifies the equilibrium concentration of oxygen and ethylene on the nanoparticle surface that, in turn, affects the Ag-SnO₂ Schottky barrier and the conductance of the nanowire.

A good example of the second mechanism is provided by Pd catalyst nanoparticles deposited on the surface of SnO₂ nanowires and nanobelts. Although one cannot rule out the operation of the first mechanism in this case also, their behavior is dominated by the spillover and back spillover processes. These are catalytic processes wherein the products of catalysis occurring on the metal particles diffuse onto the metal oxide support and the companion process in which the oxide support acts as a reagent delivery system for the metal nanoparticle, amplify the chemical processes occurring at the nanowire's surface, and dramatically modifying the nanowire's electronic behavior.

Both these mechanisms can lead to the improvement of the selectivity, sensitivity and operating temperature of nanowire-based sensing elements. More fundamentally, probing these processes leads to a better understanding of the fundamental surface properties of oxide nano-system in which some truly novel physical and chemical properties can arise from low-dimensional effects such as quantum confinement.

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Short biographies



Prof. Andrei Kolmakov specializes in surface science, transport properties, and imaging techniques of nano-objects relative to gas sensing and catalysis. He has authored or co-authored over 70 technical papers, including 2 book chapters and 4 review articles. He received his MS in physics from Moscow Physical Technical Institute in 1986. He started his research work as a staff member at the Russian Research Center Kurchatov Institute in Moscow, where he completed his PhD in solid-state physics in 1996. He currently holds an appointment in the Physics Department at Southern Illinois University at Carbondale, USA



Xihong Chen Brief Biography

Xihong Chen received her B.S. bachelor degree in physics from Shandong University, China, in 2000, and the Ph.D. degree in physics from Peking University, China, in 2005.

Dr. Chen is currently a post-doctoral researcher at the University of California Santa Barbara. Her research is focused on the fabrication of nanowire devices with special applications to nanosensors.



Martin Moskovits Brief Biography

Martin Moskovits, is Bruce and Susan Worster Dean of Science and Professor of Physical Chemistry at UC Santa Barbara. He was educated at the University of Toronto to which he returned in 1972 as faculty member. From 1993-1999 he was Chair of the Department of Chemistry.

Professor Moskovits has authored or co-authored over 230 technical papers, edited or co-edited 4 books and holds 11 patents. Over 80 graduate students and postdocs completed their studies under his supervision.

Professor Moskovits' recent research interests include surface-enhanced Raman spectroscopy and nanofabrication of nanowires with special applications to nanosensors.

Professor Moskovits is a Fellow of the American Association for the Advancement of Science, Fellow of the Royal Society of Canada and member of several Boards.