

Introduction

Hybrid materials refer to any of a class of materials in which organic and inorganic components intimately mixed. This however does not mean that simple physical mixtures of organic and inorganic compounds are hybrid materials. The rider is that the mixing be at the nanometric scale. Hybrids can either be homogeneous systems of miscible organic and inorganic components or they can be heterogeneous with dimension scales of the order of a few Angstrom to a few nanometres. At such scales, the properties of the resultant material are not just the result of the individual properties of the materials, but the scale of the interaction between the two components contributes significantly to the properties of the resultant material.

Historically, man-made materials which have both organic and inorganic components have abounded since time immemorial. C Sanchez et al refer in their review paper on hybrid materials to the dyes of the Maya, whose fastness has been recently discovered to be a result of the use of an organic pigment intercalated in a clay. There have been infinitely many other materials which are of a similar nature in history. However, the term hybrid materials has come to apply to these materials only after the development of soft chemistry techniques such as sol-gel chemistry in the 1980s.

The interplay between the organic and inorganic components offers one the possibility of designing materials to one's very exacting specification. Also, it makes it possible to endow the material with one or more specific functionalities where none existed earlier, for example magnetism, hydrophobicity or hydrophilicity, electrical properties or optical properties. The fact that soft chemistry makes it possible to synthesize these at low cost and at a low energy expenditure further endears these methods to engineers and scientists everywhere.

The ability to add functionalities to the material expands the scope of the science greatly. This also makes it very difficult for anyone to give a short introduction to the wondrous qualities of such materials. Also, the methods of their production are not particularly glamorous or special to warrant much attention. Therefore, we will in this report restrict ourselves to discussing a select few applications of hybrid materials in some detail.

Types of Hybrid Materials

The classification of hybrid materials is a very subjective thing with different authors classifying them in different manners. This is a reflection of the diversity of this field. However we will present here few of these schemes. The most commonly used method of classification uses the degree and nature of interaction between the organic and inorganic materials to define them.

- Class I hybrids: Class I hybrids are those in which the organic and inorganic components do not have any covalent or ionic bonds. The interaction is limited to van der Waals forces, pi-pi interactions and electrostatic interactions.
- Class II hybrids: These hybrid systems on the other hand have some amount of strong chemical bonding between the organic and the inorganic compounds in the form of covalent, ionic-covalent or Lewis acid-base bonds.

The other type of classification, depends on the differences in the major component of the hybrid materials. Here we have Organic-Inorganic (OI) which consist of materials in which an inorganic species is inserted or integrated in a polymer matrix.; Inorganic Organic, in which the roles are interchanged and Nanocomposites. Nanocomposites are defined as materials in which neither of the components dominates and both types of materials are dispersed at the nanometric level.

The hybrid materials can also be classified on the basis of the method in which they are made. In this classification, the hybrid materials are divided into,

- Intercalation compounds- these refer to materials in which a guest molecule/group is inserted reversibly into the host system, which is usually in the form of a periodic network. The insertion of organic groups into the inter-layer spaces in certain clays led to the first hybrid systems.
- Organic derivatives of Inorganic solids- In this class of hybrid materials, an organic group is made to react on the surface of an inorganic solid.
An example of this is the attachment of organosilanes to clays. The SiOH groups on the

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surface of the clays react with alcohols to form Siloxanes. However these are highly susceptible to hydrolysis. Hybrid materials of this type of greater stability can be formed by using $-SiX$ groups. These procedures have been used to graft fluoroalkyl groups onto magadiite, a clay, to get oil repellent compounds.

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- Sol Gel Hybrid materials- Sol gel chemistry offers the largest scope for the development of hybrid materials. In the Sol Gel process for silica liquid alkoxides are hydrolyzed in the presence of water. This leads to the formation of $Si(OH)_4$. The $Si(OH)_4$ precipitate condenses and Si-o-Si bonds are formed. These bonds form a network and a colloid is formed. The particle size increases as the reaction proceeds, so much so that the liquid medium becomes the minor phase and forming the gel. After the formation of this gel, the material may be heated to get rid of the liquid. This leads to the formation of xerogels/aerogels. This method can also be used to make specialized glasses at lower temperatures.

Sol gel chemistry is an extremely flexible method of synthesis. One can add surfactants to the mix. This will lead to the formation of the gel around the micelles formed. The surfactants can then be removed with appropriate solvents.

Also, a monomer can be added to the reaction mix. The gel is formed around the organic monomers. The gel can then be heated to polymerize the monomer. This makes it possible to create extremely well dispersed nanocomposites.

Photovoltaic Cells

The last few decades have seen a massive increase in the energy consumption of the world as the energy requirements of developed nations increases at a fast rate and the developing countries catching up faster. Conventional energy sources place significant strain on the environment and the fears of global warming and other ecological disasters are not to be taken lightly. It is therefore apt , that greater efforts than ever are being made to quicken the pace of development of solar photovoltaic cells with particular emphasis on the reduction in their cost and also increases in their efficiencies.

Conventional Photovoltaic Cells

Conventional photovoltaic cells depend on the semiconductor properties of Silicon to create and maintain a potential difference across the electrodes of the solar cell. When a photon strikes the silicon wafer, it excites a electron from the valence band to the conduction band. This leads to an electron in the conduction band and a hole in the valence band. The key to make this charge separation into a constant current is to maintain it. This is achieved by using a p-n junction diode. The creation of the junction potential minimizes the instant recombination and thus generates a current. This use of the same material for charge separation and charge transport necessitates the use of highly pure silicon. This makes the manufacturing cumbersome and increases the cost of silicon based conventional cells.

Efficiencies

There are different efficiencies defined for the operation of a solar cell. The energy conversion efficiency (η) is the percentage of the incident energy converted to power under standard test conditions. These conditions are analogous to the energy incident on the earth at the equator at noon on a clear equinox day. This value is taken to be 1000 W/m^2 . The spectrum is assumed to be the standard “air mass 1.5” spectrum. The other efficiency factors are the fill factor (FF), which is the the ratio of the maximum power point and the product of the open circuit voltage and the short circuit current. Another measure of efficiency defined for light absorption materials is the quantum efficiency. This gives the percentage of photons converted to actual electron/hole pairs. Note that this number does not in any way indicate the amount of power generated by the solar cell.

The efficiency of current commercially available solar cells ranges from 8% to 16% while laboratory solar cells are capable of delivering around 30%. It must be noted that the increase in

efficiency comes at a disproportionate increase in the costs.

The high cost of conventional silicon based solar cells necessitates the development of lower cost photocells based on alternative technologies. A lot of them have been under development for significant amounts of time, but it is only recently that they have come anywhere near being pressed into commercial service. We are going to discuss one of the alternatives based on hybrid materials which are aptly called Hybrid Solar Cells.

Dye Sensitized Solar Cells (*M Grätzel and B O'Regan*)

The fact that photo-excited dyes can be used to inject electrons into semiconductors has been known nearly for a 100 years. The first recorded demonstration of this effect was by James Moser in 1905. This effect was used by Grätzel and B O'Regan to construct the first Dye Sensitized Solar Cell in 1991. They adsorbed a Ru (II) complex dye on a semiconducting mesoporous TiO_2 substrate. The cell was constructed by depositing the semiconductor on a conducting surface like a ITO (Indium Titanium Oxide) or Au coated glass surface. The whole set up was then topped by a layer of electrolyte containing a concentrated solution of the $\text{I}_3^- - \text{I}^-$ redox couple sandwiched between another layer of conducting glass.

When a photon strikes the dye layer, the electrons in the highest occupied molecular orbital (HOMO) is excited into the lowest occupied molecular orbital (LUMO). The electron is then injected into the conduction band of the TiO_2 semiconductor layer. The electrons now pass through the external circuit, setting up a current. The oxidized dye is immediately reduced by electrons from the redox couple.

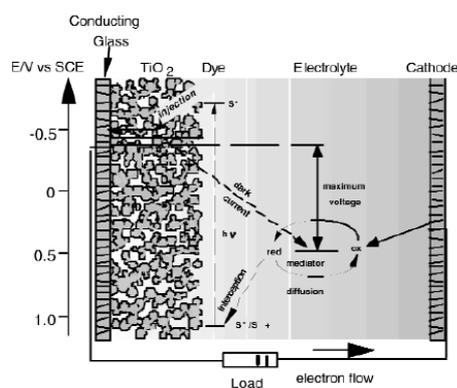


Fig. 1: Schematic of Grätzel cell.

The rate of the charge injection reaction depends on the nature of the dye used.. Various dyes have been tried out and the most successful have been the dyes containing 4,4'-dicarboxy-2,2'-bipyridyl groups. It has been found that the fastest charge injection occurs when the dye has a suitable anchoring group such as the carboxylate or the phosphonate group. These groups provide good overlap between the LUMO of the dye (π^*) and the unoccupied conduction band of the TiO_2 substrate. The recombination of the excitons is prevented by the creation of a surface electric field due to the proton transfer from the carboxylate groups.

The maximum voltage available is the difference between the potential for the redox reaction and the conduction band energy of the TiO_2 substrate. For maximum generation of electric power, it is essential that the exciton generation efficiency should be large over the visible spectrum. The dye mentioned already is one of them. The fill factor of this cell was found to be very high and the overall efficiency achieved was around 10%. The efficiency was found to be more or less constant over temperatures ranging from 20-60%.

Nature of the TiO_2 substrate

The nature of the TiO_2 substrate is an important variable in the working of the solar cell. The TiO_2 precipitate is formed by the controlled hydrolysis of Ti (IV) hydroxides. The sol formed is baked at 250 deg C. The solvent is removed and after the addition of a binder, it is laid on the conducting base with a thickness of a few microns by screen printing followed by sintering at 450 degC to ensure electrical conductivity. The mesoporous nature of the TiO_2 is very important for the functioning of the cell, as it increases the surface area available for adsorption of the dye and thus the area available for light adsorption. In this, the cell is a lot like the thylakoids in chloroplasts as light absorption occurs at multiple layers. Hence, the Grätzel cell is also sometimes called the bio-mimetic solar cell.

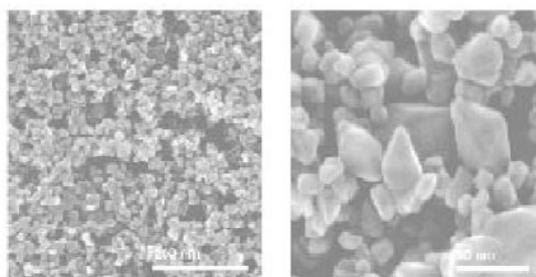


Fig. 2: SEM image of Titania surface

The morphology of the TiO₂ substrate plays an important role in the working of the solar cell and is the focus of a lot of the current research in hybrid photocells. In the most basic form as a film of nanocrystals, it is observed that the cell is able to deliver only a maximum voltage of upto 0.7V as against a theoretical maximum of around 1V. Various morphologies have been tried such as TiO₂ nanorods, TiO₂ nanocylinders etc. have been attempted with varying degrees of success. This is primarily due to the fact that although the nanocrystalline surface allows for high surface area, the random nature of the structural interaction between crystals allows electrons to be scattered, thus limiting the further improvement of the efficiency. It has been found that, if instead of the TiO₂ nanoparticles, if ordered systems of nanotubes are used, then the voltages generated are higher. Several non titania alternatives like ZnO etc have also been tried with different levels of success. The mechanism of charge transfer through the titania is as yet not known. The earliest work assumed the surface to behave like a perforated electrode. However, this view has been now discarded as the results are not in line with experiment. Current research treats the titania substrate as an ensemble of titania particles, with the electrons jumping from one electrode to the other.

The Back Reaction

The initial design of the dye sensitized cell has a Iodide-Triiodide reaction couple that acts as the electron return mechanism. However, this presents serious problems in the manufacture of the cells as the presence of a liquid electrolyte produces introduces problems like leakage, evaporation and decay of the solvent. These problems are not serious when only small photocells are made. However, for a solar cell technology to be commercialized requires that it be producible in large modules. It is here that the liquid electrolyte turns out to be a big problem. Therefore another topic of current research is to replace the liquid electrolyte by either a semi-conducting oxide or a organic semiconductor. The ease of processing and lower cost of the organic polymer automatically suggest them. Instead of the redox couple, people have tried using CuI and CuSCN as also some Arylamines. These electron returners have the advantage of easy manufacture, but they lose out on the efficiency. Another thing to be kept in mind while making these choices is that the energy gap should be such that, the electron transfer is energetically allowed.

Gebeyehu et al have suggested the use of a single conducting polymer instead of a separate sensitizer and electron returner. This idea is still in the nascent stages and high efficiencies have not yet been achieved.

The Sensitizer

Another area where there is scope for development is the dye sensitizer. The primary problem is that the dyes are not equally sensitive to all wavelengths. Currently two dyes are commonly used in research, one of them is N3 and the other is called black dye. Both these dyes have very good spectral response to almost all the visible wavelengths except at very high wavelengths.

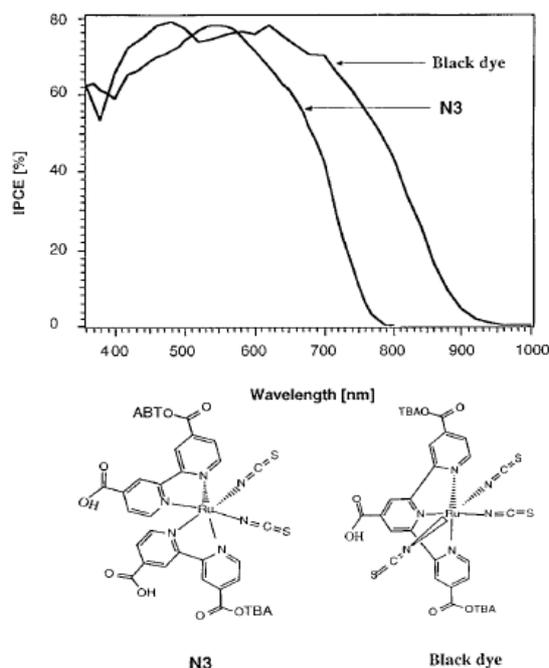


Fig. 3: Spectral response of N3 and Black Dye

A workaround for this is using multiple dyes in tandem, each one sensitive in a particular set of wavelengths. It is also essential that maximum sensitivity be in the visible wavelengths. The sensitivity of the cells has been extended to the red and infrared parts of the spectrum by using porphyrin and phthalocyanine mixtures. Another important quality for the sensitizer is that it should be able to last a large number of reactions, around 10^8 , to give a life of around 15-25 years to the solar cell.

Quantum Dot Solar Cells

The wavelengths comprising solar light have energies ranging from 0.5 to 3.5 eV. The values which are lesser than the bandgap are lost while those above the band gap impart a kinetic energy equal to the difference to the electrons and holes. This leads the effective temperature of these holes and electrons to be extremely high compared to the rest of the lattice. Such electrons and holes are called hot electrons and holes. This excess energy is then converted to heat causing a large part of the energy to be wasted.

The conventional solution for this effect has been to use multiple junctions, each at a different band gaps corresponding to different wavelengths of light. However, as expected, this leads to a great increase in the cost. Another way is to use the process of impact ionization to increase the number of excitons generated by each electron. In impact ionization, if a material is irradiated with a photon of energy greater than $2 E_g$, the electron is excited to a higher orbital. It then releases E_g to return to the base conduction band. This E_g is used to excite another electron to the conduction band. Therefore as a result, it is theorised that one gets 2 excitons for a single photon. However, this effect is not very efficient in bulk semiconductors owing to a variety of effects.

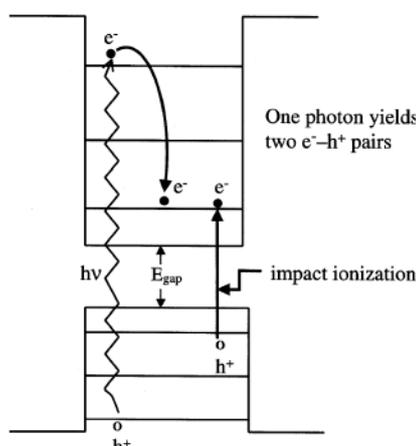


Fig. 4: Impact Ionization in a semiconductor Quantum Dot

Quantum dots are extremely small particles of semiconductors, of the order of 50-100 molecules. At these sizes, the energy levels are still discrete. This allows the electron to “cool” slowly enough for the impact ionization to occur. Also the energy levels and energy gap of the quantum dots depends both on their size and shape, this allows us to consider the possibility of engineering the quantum dots to our necessities.

Studies by Schaller and Klimov have suggested, that the PbS quantum dots can indeed be used in photocells as exciton generators, and if properly engineered, will provide a significant boost to the overall power efficiency.

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A Nozik suggests a couple of implementations of Solar cells using quantum dots. He suggests that they be used either as an intermediate between the p and n junctions of a silicon based semiconductors. Other possibilities involve using them as additional sensitizers in a dye/TiO₂ solar cell and using them in a donor/acceptor bulk heterojunction configuration by dispersing the quantum dots in a semiconducting organic polymer.

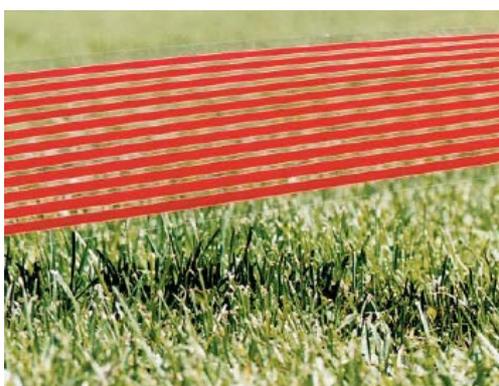
Studies have been conducted on all three types of solar cells, with promising results. Although the efficiencies of these cells are still on the lower side, it is expected that proper design of the morphology of the quantum dot will lead us eventually to much higher efficiencies.

Commercialisation of Solar cells

The efficiencies of this new class of solar cells reaching 5% and above, has also led to the beginning of the commercialization of these cells. Various companies in the United States and elsewhere are working actively to make these solar cells available to the mass market. Primary amongst them is Konarka Technologies of USA, which is commercialising a version of the Grätzel cell, printed on plastic rolls, using manufacturing technologies originally invented for the production of photographic film and also other technologies like inkjet printing etc. Another company Nanosolar inc. is using a different technology but pretty much the same manufacturing technology for the same ends. These new solar cells offer comparable overall efficiencies to conventional Si technologies at a fraction of the cost and with more flexibility. With the solar cell being on a flexible transparent sheet of plastic, it becomes possible to laminate exposed surfaces on automobiles, electronics and buildings with a transparent and for all practical purposes invisible coating which contributes to the power requirements of the device/ habitation.

Future applications which are not very far away at the current rate of technological development are photocells which can be mixed into paint. Or sprayed on the surface of choice, in a simple process.

The only major problem existing currently with these cells is the durability. The chemicals currently used are sensitive to oxygen and have a shorter lifespan than Si based solar cells. This makes it necessary to have hermetically sealed solar cells. However, now that the industry has gotten in on the act, we can be certain that the day will not be far away that these technologies will be perfected and they become a fixture in our lives, solving to some extent the problems of our ever increasing energy needs.



Konarka Technologies' solar cell printed on plastic film (MIT Technology Review, August 2004)

A Chemical Tongue

Taste is one of the final frontiers in man's efforts to simulate his senses artificially. Various methods have been suggested which have achieved various degrees of success. We will in this report describe one such effort to design a chemical tongue based on Polyaniline- Rupy (mer-[RuCl₃(dppb)(py)](dppb)^{1/4} PPh₂(CH₂)₄PPh₂;py^{1/4} pyridine)thin film by M. Fereira et al.

Polyaniline is a conducting polymer. It exists in many forms, but the most stable form is the emeraldine form which has exactly half the amine bonds reduced to the imine bond. In the presence of protic acids P-Ani behaves as a p-doped semiconductor.

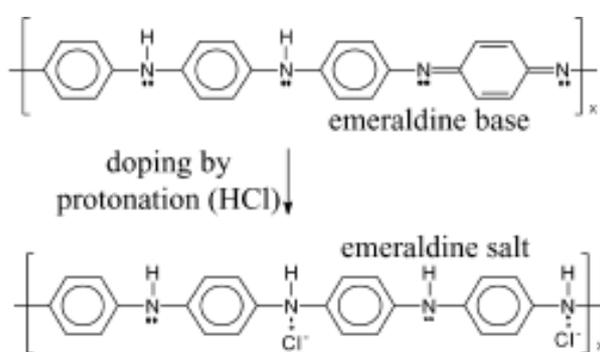


Fig. 5: Emeraldine in the protonated form

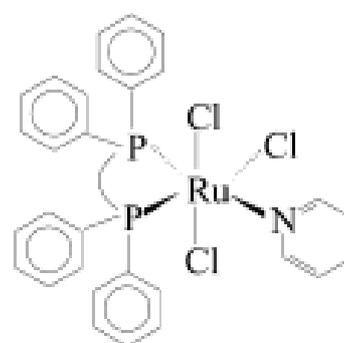


Fig. 6: Rupy

The working of the chemical tongue described is based on the Langmuir Blodgett film of the mixture of the two. An LB film is a film containing one or more layers of an organic material deposited on the surface of a solid substrate like glass. This is achieved by immersing the solid substrate into the liquid and then removing it at an extremely low rate. Multiple layers are obtained by multiple immersions.

The P-Ani Rupy LB film is formed by first dissolving the emeraldine in m-cresol and chloroform. This solution is filtered to get rid of any undissolved solute. The desired quantity of Rupy is then added and then a solid substrate, usually ITO coated glass, made acidic (pH=2.0) is dipped into the solution mix. Multiple layers can be formed this way by repeating the process many times.

Properties of the P-Ani- Rupy LB layers

The Rupy tends to oxidize the P-Ani by increasing the number of quinoid groups. This change manifests itself in the form of changes in the electrical behaviour of the P-Ani. The surface potential, the dc conductivity of the P-Ani change significantly. For different percentages of Rupy in the mix, the change is observed to be non linear and non monotonic. For example, the plot of the dc conductivity measured by using a two finger probe has a minima at 10% Rupy.

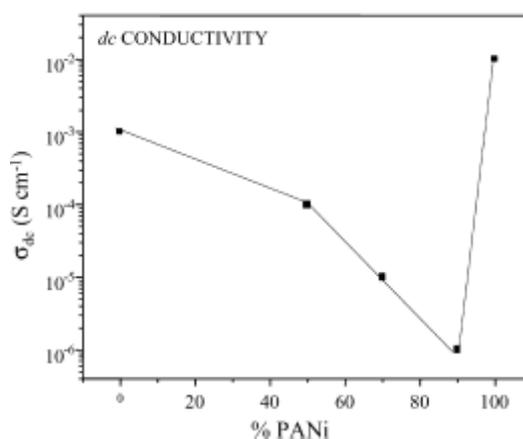


Fig. 7: DC conductivity of P-Ani-Rupy film as function of Rupy content

It has been proven experimentally that this change is due to better molecular interaction between the two materials at 10% rupy. When different solutions of different proportions were left to stand for 4 hours, it was found that, while the 10% solution was stable and clear, there were signs of phase separation in the other proportions.

The Chemical Tongue

It has been noted that the properties of the film are different for different for different concentrations. It is in fact this fact that is used in the design of the chemical tongue.

For the chemical tongue 4 P-Ani, rupy films of different proportions ranging from 100% rupy, 70 and 90 % P-Ani and 100 % P-Ani of 11 layers were formed. The film was fully dedoped by treating it with a solution of pH 5.8.

To demonstrate the use of these films as tongues they were dipped in liquid solutions of NaCl, Sucrose, quinine etc. It was found that the dipping caused a marked change in the capacitance of the films, when measured by an impedance spectrometer. This method was used as it does not require a reference terminal and can be implemented in a miniature system.

It was found that the change in the capacitance depended on both the proportion of rupy in the film as well as the substance in the solution.

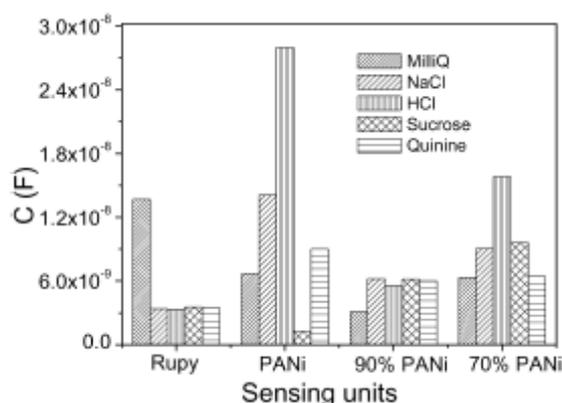


Fig. 8: Capacitance values for different analytes

It is clear from the graph that the sensor is not very selective, as the difference in values is often not too significant. This, the authors suggest can be compensated for by using 4 or more of the films with different levels of rupy. The values for different substances then could form the basis of a “fingerprint” for the substance. The simplicity of this method makes it possible to do the calculations with a relatively simple circuit.

The sensitivity of the film to the common tastes were found to be most satisfactory. All the solutes were detected at 8 μM . This compares very favourably with the human threshold values of 10mM for the detection of common salt and sucrose and 8 μM for quinine.

Thus the interaction between rupy and P-Ani make it possible to have a small economic and reasonably accurate chemical tongue.

Photochromic hybrid materials

Photochromism is defined as the reversible interconversion of a chemical species between two states with different absorption spectra. This change is usually brought about by light. Photochromic molecules belong to various classes. The ones we will be focusing on are spiropyrans and spiro-oxazines.

The spiro form of an oxazine is a colourless dye. The conjugated form is separated from the other aromatic part of the molecule by a sp³ hybridized carbon called spiro-carbon. When irradiated with UV light, the bond between spiro carbon and the oxazine part breaks, the ring opens, the carbon becomes sp² hybridized and becomes planar, the aromatic group rotates and aligns its pi orbitals with the rest of the molecule and therefore a conjugated system forms which has capability to absorb photons of visible radiation and thereby appear colourful. When the UV source is removed, the molecule relaxes back, the bond between carbon and oxygen is reformed, the spiro carbon again becomes sp³ hybridized and the molecule becomes colourless as before. The reversible reaction with a change in colour suggests that they may be good materials for use in a optical molecular switch.

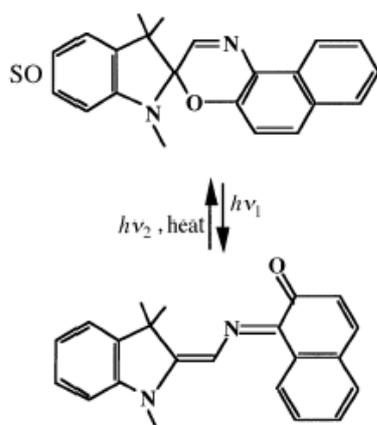


Fig. 9: Spiroxazine

Photochromic dyes tend to be unstable in their open state. Their lifetime is negatively affected by UV exposure, since the open form is susceptible to degradation by oxygen and free radicals. Incorporation of dye into a polymer matrix is one way of prolonging their lifetime. These dyes have the appearance of a crystalline powder. To achieve the colour change they have to be dissolved in a solvent or dispersed in a suitable matrix. Therefore work is on in using them in an inorganic matrix which stabilizes them so that they can be used in circuits.

Photochromic hybrid materials for fast optical switches

As we have seen Photochromic molecules like spirooxazines (SO) and spiropyrans (SP), undergo large structural changes after absorption of photon. The rates of both light driven structural changes and of the back reactions are sensitive to the environment in matrix.

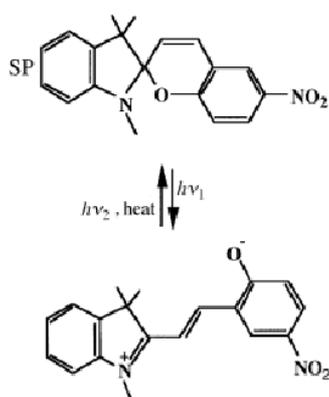


Fig. 10: Spiropyran

The advantages of hybrid systems are high photochemical stability, flexibility of the host matrix in allowing molecular rearrangement of dyes etc.

In different chemical environments, competition between direct and reverse reactions is observed. Many groups have suggested that hydrophobic/hydrophilic balance (HHB) of the hybrid matrix is an important factor in controlling the competition between direct and reverse reactions.

Usually spiropyran- or spirooxazine doped matrices exhibit slow thermal fading (reverse reaction) because of steric constraints and /or the stabilization of the polar open form of the molecules through dye/matrix interactions. E.g. hybrids synthesized from poly(N-N-dimethylacrylamide) having spiropyran on the side chain and cross-linked by silica produced through the hydrolysis TMOS exhibit direct photochromism upon irradiation. Their photoisomerisation behavior indicates a preferred solvation of the spiropyran moieties by the organic polymer host rather than by the silica component.

For photochemical devices, tuning between strong and fast Photochromic coloration and a very fast thermal fading is needed. This can be done by careful adjustment of the interface experienced by dye.

Some Developments in Fast Photochromic Response

Work of Schaudel et al has shown that very fast thermal bleaching can be observed in soft and strongly hydrophobic matrices, fully free from OH groups, synthesized from co-condensation between MeHSi(OR)_2 and HSi(OR)_3 precursors.

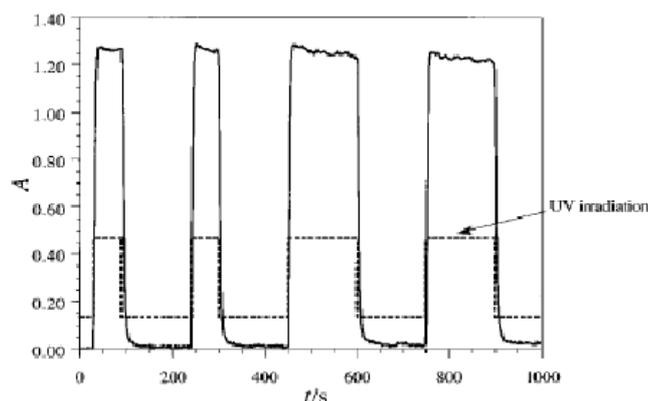


Fig. 11: Optical density vs time of SO embedded in strongly hydrophobic matrices

Inside mesostructured hybrid materials made from a silica source and amphiphilic block copolymer templates (Pluronic), SP and SO exhibit direct photochromism and quite fast kinetics.

Recently, photochromic nanocomposite coatings based on an epoxysilane (GPTS) network former, and different bisepoxides CHMG-non polar or PCF-polar as spacers, an organic amine (isophoronediamine) as thermal cross-linker and spirooxazines as photochromic dyes, have been developed. In such composites the dye spacer interactions have a significant influence on the switching behavior. This effect in which switching times increase with increasing spacer content and with increasing the polar character of the dye molecules, maybe used to tune the photochromic behavior of spiroxazines for different applications.

Optical processing with molecular switches

We live in a world where enhanced transmission capacities and speeds are the buzzwords. So a gradual transition is taking place from electrical to optical networks. Large volumes of data encoded on optical signals can be sent over long distances rapidly. Currently their propagation along specific routes is ensured by a combination of optical fibers and optoelectronic switches. But it is increasingly becoming apparent that this interplay between the routing electrical simulations and the traveling optical signals will not be able to support the terabit-per-second capacities that will be needed in the near future. Electrical inputs cannot handle this. So techniques to control optical signals must be developed. Molecular switches are promising candidates.

Basic switching operations

The colorless spiropyran state SP changes into the purple merocyanin form ME on irradiation with UV. The SP state can be restored back from ME state by either irradiating ME state with visible light or just by keeping it in dark. Alternatively SP switches to the yellow-green protonated merocyanine MEH on acidification. MEH returns to SP state on irradiating with visible light. The addition of acid to ME produces MEH, and the treatment of MEH with base restores ME.

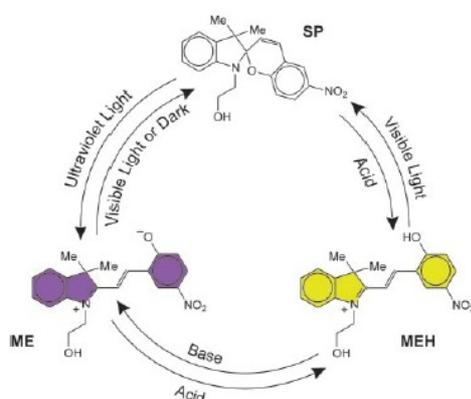


Fig. 12: Interconversion between states SP, ME and MEH

The switching process is entirely controlled by optical inputs. It makes use of the fact that both the isomers have distinct absorption properties in the visible region. In MeCN, the purple state ME has a strong absorption band at 563 nm and can block an incident signal of this wavelength. The colorless state on the other hand, does not absorb at 563 nm and will allow it to pass through.

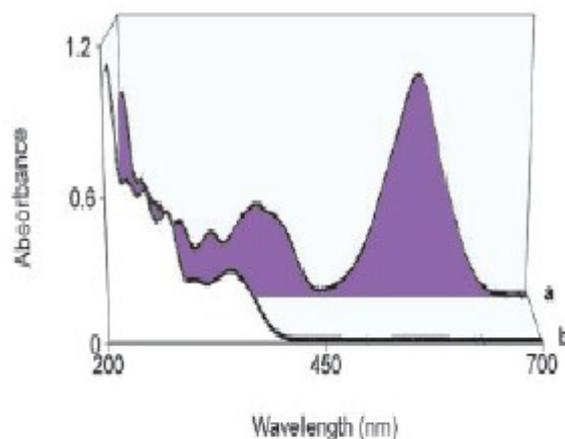


Fig. 13: Absorption spectra of SP recorded after (a in Lower) and before (b in Lower) irradiation at 254nm for 5 min.

The photoinduced transformation of SP into ME state is extremely fast and involves the formation of colored intermediaries.

Time resolved laser spectroscopy has demonstrated that, in case of the parent 6-nitrospiropyran, colored species can be detected within 10ps from irradiation. Thus, an optical input addressing SP can be transduced, at least in principle into an optical output on a picosecond scale. So this molecular switch is particularly attractive for digital processing at molecular level.

To understand how these switches work we will take an example of one of the basic switching operations NOT (complementing). Ultraviolet irradiation will correspond to the input and the measurements at the detector correspond to the output.

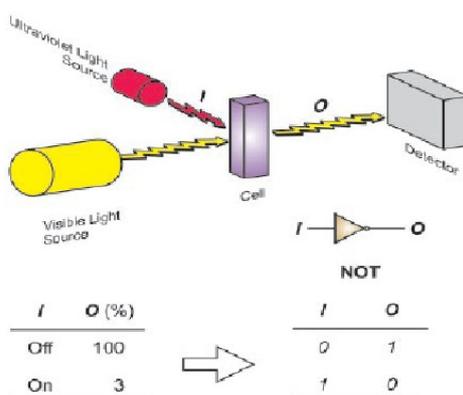


Fig. 14: Basic NOT operation implemented using hybrid optical switches

In this setup a monochromatic signal passes through the cell to the detector. The cell contains a solution (MeCN, 10^{-4}) of the molecular switch. The irradiance of this solution with UV induces the interconversion of SP to ME. If the input is turned off, SP reverts back to ME.

When the molecular switch is in the “non-absorbing” state SP, the intensity of the optical output reaches 100%. It reduces to 3% when the system is in ME state which is an “absorbing state”. Thus, the optical output (O) switches between low and high values as the optical input (I) is turned on and off.

Some more examples of these switches (using combination of basic gates)

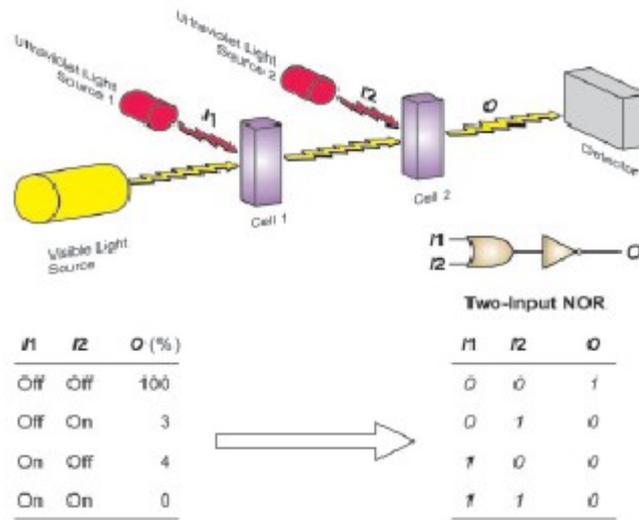


Fig. 15: Two input NOR

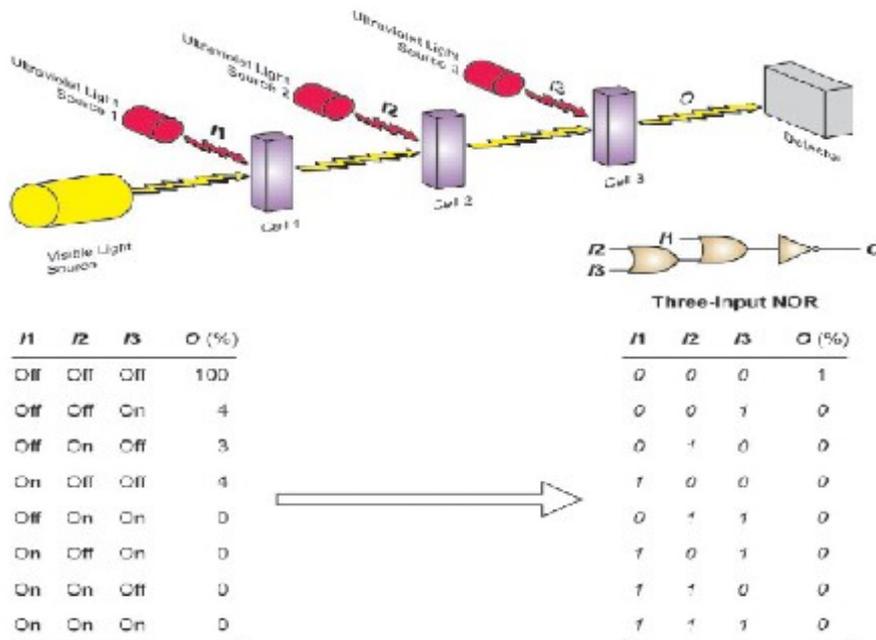


Fig. 16: 3 input NOR

Conclusion

A topic like hybrid materials is too vast a topic to be covered comprehensively. The three systems that we have presented to you are made possible only due to the interaction between organic and inorganic components. There are a lot of other Hybrid Materials which have equally interesting properties. It is possible with these hybrid materials to achieve a lot of things that were once upon a time thought impossible.

These materials are extremely innovative, true. But however, nature as always is a few billion years ahead. Our bones are the most wondrous examples of hybrid materials. They are strong, smart and self repairing, properties any engineer would die for.

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