

Theme article : Light and Light based Technologies for Day to Day Life

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Light and Light based Technologies for Day to Day Life

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Since the year 2015 has been declared by the United Nations as the International year of light, it is a good time to consider the role of light in our lives and in modern technologies. A short summary of the current situation and historical perspective is offered in the following paragraphs.

Light plays two major roles as a supplier of energy and a carrier of information. The energy aspect has led to the development of solar light capture. The mature and commercially viable technology is based on silicon semiconductor photovoltaic cells, which goes back to the time of the first journeys to the moon. It is only now that the scale of manufacturing has risen to the point that such cells are economical enough to be employed in domestic situations in some countries. Still, single crystalline silicon is not cheap to produce.

First, quartz sand and coked coal have to be heated to around 2000° in an electric arc furnace. The impure silicon so obtained has to be purified to extremely high levels before it is drawn into a near-perfect single crystal, all of which requires large inputs of energy. Therefore there is ample room for other approaches.

Organic/inorganic dye sensitized photoelectrochemical cells containing nanoparticulate semiconductors such as titanium dioxide has grown as a competing technology over the last three decades. Once photoexcited, the dye can inject an electron into the titanium dioxide matrix which can be routed through an external load to a counter-electrode. In the meantime, the oxidized dye picks up an electron from a redox shuttle (usually iodine-iodide). Diffusion of the oxidized shuttle to the counter-electrode finds an electron waiting for it so that the electrical circuit can be completed. There is a Sri Lankan contribution to these dye

sensitized photoelectrochemical cells from the pioneering work of Professor Kirithi Tennakone at the University of Sri Jayawardenapura, University of Ruhuna and the Institute of Fundamental Studies in Kandy. The last few years have seen the emergence of organic-inorganic perovskite-based solar cells (with or without titanium dioxide) which have the advantages of inexpensive solution-processing and rather high efficiencies but which still face concerns over long term stability and heavy metal content. Taken together, it seems quite probable that renewable energy without dependence on fossil fuels and without consequences for climate change can now come directly from the sun.

Most of us receive the bulk of information for living, through our eyes during the day. Our other senses play secondary roles. This



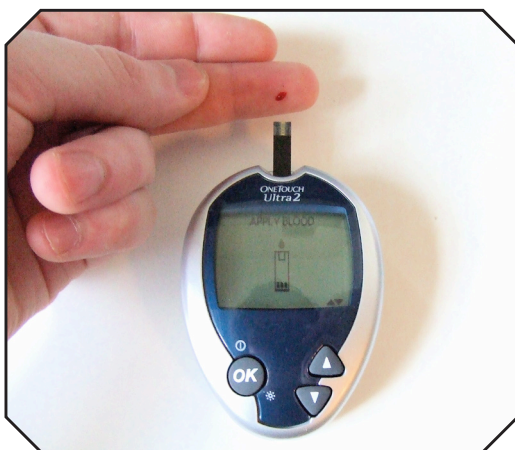
information reception continues during the early part of the night, thanks to artificial illumination. Flames, incandescent bulbs, fluorescent tubes and light emitting diodes have lit up the world around us at various periods of history and circumstance. Instead of simply illuminating objects, light can be employed within active devices to directly create images for our consumption. Photographic film, cathode ray tubes, xerographic media, liquid crystal displays, plasma devices and light emitting diodes have invaded our lives in the form of documents and screens of televisions, computer terminals, personal computers and smart mobile telephones. In more public places such as cinemas and streets, intense illumination sources such as arc lamps also play a role. Though less visible, the information carrying aspect of light is also vital to modern broadband data

transmission since fibre optic networks are literally embedded in our societies. Each of the above points has given rise to a large number of major industries, worth many billions of dollars, servicing virtually the entire world.

There are other less visible light based technologies, sometimes serving in life or death situations everyday worldwide, which I would like to concentrate on in the remainder of this article. For instance, some medical diagnostic

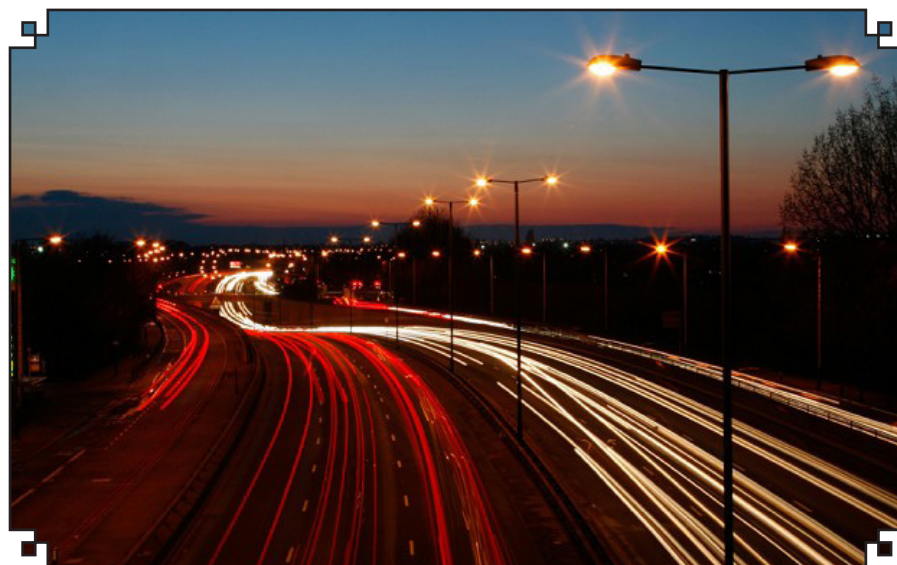


systems depend on fluorescent molecules to measure and signal the number of various atoms and molecules that keep us alive. When we are not too well, the numbers of these components are altered. Signalling these altered numbers, say those of sodium ions in our blood, to a clinician allows disease diagnosis and treatment. Such signalling works on the basis that



the designed molecules produce an emission intensity which is larger if they encounter a higher concentration of sodium ions. The serum is presented to these fluorescent molecules after passage through a micron filter so that the blood cells are removed. Light emitting diodes provide the necessary excitation energy. Corresponding applications in veterinary situations also exist. These have led to a small number of industries earning hundreds of millions of dollars.

The molecular photoscience underlying the above paragraph deserves to be outlined. The fluorescent molecules are constructed in three parts which are connected together. A fluorescent dye takes care of the interactions with light, whether it is the exciting light or the emitted fluorescence. A receptor deals with the capture and release of the sodium ion. A spacer unit joins the fluorescent dye and the receptor but keeps them apart at a small distance. When the exciting light is absorbed by the fluorescent dye, the energy ingested can be used to instigate a chemical process. Given the appropriate redox potentials, an electron is dug out from the receptor, transferred across the spacer unit and injected into the fluorescent dye. Thus the fluorescent dye is unable to give out any fluorescence light owing to the photoinduced electron transfer (PET) process. Such PET processes lie at the heart of green plant photosynthesis anyway. Thus in the absence of a sodium ion, the three-module fluorescent molecule is held in a dark or 'off' state. However, when the fluorescent molecule meets and captures a sodium ion in the receptor unit, the positively charged sodium ion electrostatically holds



back the electron from transferring to the fluorescent dye unit from the receptor. The shutting-down of the PET process allows the excitation energy to be emitted as fluorescence light. Therefore, in the presence of a sodium ion, the fluorescent molecule switches to an 'on' state. This is the light signal which we see.

The examples considered in the previous two paragraphs involve the fluorescent molecules being embedded in small transparent plastic chips which have millimetre scale channels along which samples of freshly drawn blood would flow. In addition to such *ex vivo* applications (which have easier passage through medical watchdog agencies during the accreditation process), there are new cases emerging where the fluorescent molecules are immobilized on the tips of optic fibres placed within a cannula in a vein, to allow continuous monitoring of the blood. Such monitoring can be really useful in intensive care units where a sudden deterioration of a patient's condition can be picked up and remedied urgently. The case of glucose monitoring has been

particularly successful. Problems of white cell attack and subsequent covering up of the fibre tip, which stymied previous efforts along this line, appear to have been beaten by the use of new biocompatible hydrogel coatings.

However, molecules of nanometric size and suitable biocompatibility can even operate inside living cells (alone or within tissue sections) to signal the intracellular concentrations of various atoms and molecules. The fluorescence emission and the exciting light have no difficulty in connecting the intracellular world with our macroscopic domain, owing to the optical transparency of most cell components. Even though the requirement of fluorescence microscopes for these examinations limits their wide usage, the results obtained go to the heart of cellular behaviour. For example, the language of internal messengers inside cells (such as waves of calcium ions) provide the underpinning to many biotechnology industries worth billions of dollars. Here is a light based technology which opens a window on life processes at the

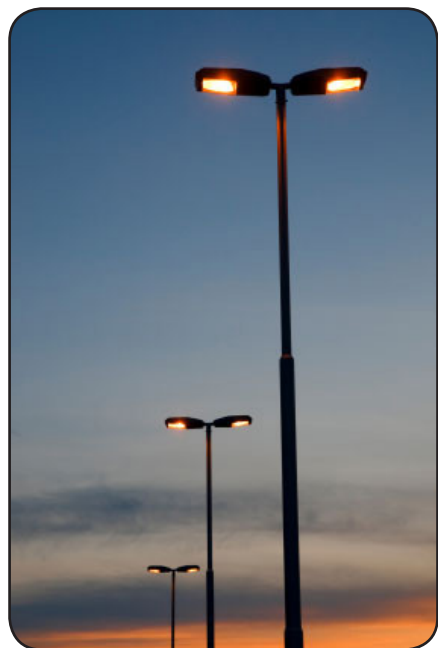
cellular level in atomic or molecular detail.

There are even less visible light based science discoveries which await refinement and improvement to the point of societal impact. Commercial and political will also have their parts to play. Now there are fluorescent molecules which can perform computational operations. Though rudimentary by the standards of silicon semiconductor technology, these molecules possess the exclusive advantages of being small and biocompatible enough to operate within living cells (as mentioned in the previous paragraph). For instance, some of these molecules will emit a blue fluorescence signal only if they simultaneously meet protons and sodium ions at concentrations above certain thresholds, so that we have a Boolean AND gate operating with proton and sodium ion inputs and a fluorescence output. A power supply in the form of an ultraviolet light needs to be available. Since life related processes usually involve many synergies, such AND gates can directly detect important situations. For instance, higher than normal levels of sodium ions, potassium ions and protons occurring simultaneously might indicate a serious loss of electrolyte regulation such as what might arise from a failing kidney. A single 'high' fluorescence signal from a three-input AND gate would indicate this condition. Such a direct test could provide quick screening of large populations of people without the need for a medical doctor. However, only the patients yielding a positive test result can then be examined by a medical doctor so that false positives can be weeded

out and proper treatment given to those who need it. In such contexts, 'lab on a molecule' AND gates can save a doctor's time – a precious resource.

Another application of molecular logic based computation which exploits the small size of fluorescent molecules is to aid drug discovery programs. Many of these employ sub-millimetric plastic beads as carriers of the drug candidates. These beads need to be tagged so that their identity is known throughout the drug discovery and evaluation process. However these beads are too small to be tagged by semiconductor-based radiofrequency identification (RFID) chips, which would otherwise have been the obvious choice. Molecular computational identification (MCID) tags come to the rescue. Their fluorescence response pattern to a given set of chemical input commands provides an identity of sufficient diversity to tag a large population of plastic beads.

Certain types of these fluorescent



molecules are now able to perform some of the same computations that all of us do when we observe the world around us, such as detecting the edges of approaching objects so that we can quickly assess if they are friend or foe and then respond accordingly. In this instance, these molecules need to be spread out on a sheet of paper so that a graphical user interface is available, akin to a mouse driven computer screen or a phone touch screen. In this instance, the small size of the molecules means that huge numbers of these operate in a massively parallel fashion on a sheet of paper of centimetre dimensions in order to perform the large area computation.

Some of these fluorescent molecules are also able to perform some of the conscious information processing that we have done since childhood. An example is the creation of outline drawings from a template, just like a portrait artist sketches a person in front of him or her. However, the molecules do not draw the outline directly like an artist would. Rather, they first display a photograph, followed by a slight expansion of it. Finally, they erase the original photograph to leave the regions of slight expansion in the form of thin lines. While it is true that the molecular drawing algorithm is inefficient, it is remarkable that simple molecules can emulate a little piece of human behaviour. Of course, each of these designed fluorescent molecules can only perform one human computing operation, whereas we can perform many such operations repeatedly. Nevertheless, the gap between molecules and humans concerning information handling does not seem as wide

as it was previously assumed. For the purposes of this article, it means that the combination of light and molecules can provide a wide gateway into light based technologies for human benefit.

The above paragraphs have summarized how deeply rooted light and light based phenomena are within our societies and ourselves on a day to day basis. It is no wonder then that societal impacts have emerged and will continue to emerge. These examples of light based science discoveries and technologies will only grow if bright young people join in this worldwide adventure and continue their participation into later life.

The support of the Department of Employment and Learning of Northern Ireland, Engineering and Physical Sciences Research Council of the United Kingdom, European Commission, McClay Trust, Procter and Gamble Company, Japan Society for the Promotion of Science and Roche-AVL and the guidance of Errol Fernando, Satish Namasivayam, Vincent Arkley, James & Jadwiga Grimshaw and Ron Grigg are gratefully acknowledged.



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