Solar Control Coatings for Reduced Energy Consumption

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Our modern society requires always-increasing amounts of energy. This trend is not sustainable, both for energy resources availability and impact on the environment. It is, hence, essential to find ways to decrease our energy consumption. The use of solar control coatings (SCCs) on glass windows of buildings is an effective measure to achieve this, by changing the optical properties of the glass and control the amount and type of light allowed in or out. This essay will look at existing commercial SCCs, and exciting new work on smart SSCs for variable climates.

Solar Control Coatings (SCCs)

SCCs are thin deposits of appropriate materials, which interact with electromagnetic radiation, either absorbing or reflecting part of it. The interaction with infrared light, which accounts for more than half of the energy from sunlight, is particularly important. If SCCs are applied to a window, they can control the amount of energy going through it, i.e. controlling the radiation from the sun which enters the building and/or the energy from heat escaping the building.

Optical Properties

To have a practical use, SCCs must have high transmittance in the visible, to let light pass through the window. The optical properties in the infrared, on the other hand, may be different, depending on the application, i.e. in which kind of climate the coatings will be used.

For cold climates, the ideal SCC should maximise the solar radiation entering the building while minimising heat escaping from it; this is achieved using the so-called *low-E glasses*. These glasses have coatings which are transparent to short wave infrared radiation, allowing most energy from the sun to pass through. They will, however, reflect long wave infrared radiation, meaning that most of the energy coming from the heating, which has longer wavelength, will not pass through the window and escape the building.

For warm climates, on the other hand, SCCs should minimise solar radiation entering a building; to do this, the materials should be highly reflective in the infrared region. These kinds of coatings are normally referred to as *heat mirrors*.

Commercial Products

Both low-E glasses and heat mirrors already exist as commercial products; indeed major glass companies such as Pilkington-NSG and Saint Gobain make windows with these coatings, which already lead to substantial energy savings.

Low-E glasses are usually based on transparent conducting oxide materials such as tin dioxide, while heat mirrors are based on thin layers of metals or alloys, i.e. a 3 - 5 nm thick layer of silver.

A Step Forward

As stated above, glasses with these optical properties already exist. However, there is still room for improvement, developing more efficient materials with enhanced behaviour, leading to greater reductions in energy consumption.

The main limit of the SCCs described above is that they can be used only for one type of climate, i.e. either in very cold or very hot weather conditions. Many areas such as central European countries and many US states, however, have very cold winters and very hot summers; in these cases, a SCC that could be effective in both seasons would be ideal.

Vanadium Dioxide (VO_2)

A material that potentially has the characteristics of all-year around solar coating is vanadium (IV) oxide (VO_2). VO_2 is a thermochromic material, meaning that it changes its optical properties with temperature. This change is due to a phase transition, more specifically a metal to semiconductor transition (MST). At room temperature, VO_2 exists in the monoclinic phase (M), which behaves as a semiconductor. At higher temperatures, on the other hand, VO_2 is stable in the rutile (R) phase, which has the properties of a semi-metal. The transition temperature (T_c) is 68 ^{o}C and the transition is completely reversible.

Such MST causes a significant change in the electric properties, with the R phase being much more conductive than the M one; at the same time, however, the optical properties are also heavily affected. VO_2 (M) shows a very low infrared reflectance (high transmittance), while VO_2 (R) has a much higher infrared reflectance (lower transmittance). Meanwhile, the visible optical properties remain virtually unchanged.

VO_2: the Potential

Due to its thermochromic behaviour, VO_2 has the potential to be a SCC. If applied to a glass window, at low temperature – a cold winter day – most of the infrared light/energy from the sun will go through, as the material is in the M phase. At higher temperatures, on the other hand – a hot summer day – VO_2 will be in the R phase, which will reflect a significant proportion of the sun's infrared energy. In this way, the energy gain from sun light will be maximised in winter and minimised in summer, leading to reduced costs and energy consumption for winter heating and summer air conditioning.

VO_2: the Challenges

Despite the potential, however, there are still some issues, which stop VO_2 from being used in SCCs. Specifically:

- The T_c value is too high for the material to have a practical application - ideal T_c should be around 20-25 ^oC.
- The material absorbs in the visible, and has an unpleasant yellow-brown colour, not appealing for a window coating. Moreover, the transmittance of the visible light is also reduced.
- Thin coatings, which allow a high transmittance in the visible and whose colour is not too strong, do not show a great change in the reflectance and transmittance in the infrared; the energy saving associated with it, therefore, would not be significant.

Many studies have been performed to address these issues and make VO_2 suitable for SCC use.

Decreasing the T_c Value

Several researches have shown that T_c can be changed with the introduction of appropriate dopants into the VO_2 structure. The use of tungsten, in particular, proved to be very effective in decreasing the temperature - T_c values as low as 5 ^oC were observed. Other effective dopants were niobium and fluorine.[1]

Other studies also showed that the morphology of the coatings could affect the value of T_c. For instance, in thin films prepared by Chemical Vapour Deposition (CVD) it was observed that the use of surfactants during the deposition had an effect on the surface morphology, and this led to a decrease in T_c. In fact, a T_c value of about 30 ^oC was seen, without the use of any dopants.[2]

A More Acceptable Colour

The brownish colour of VO_2 is not suitable for its use as window coating; attempts have been made to change it to a more acceptable hue. Interesting results were obtained by incorporating gold nanoparticles (Au NPs) into the VO_2 structure.[1]

One of the features of Au NPs is Surface Plasmon Resonance (SPR), due to the interaction of free electrons with light; such interaction gives NPs a colour, which depends on their size and shape. In the case of Au NP coatings, the colour may also depend on the host matrix. When Au NPs were included into a VO_2 matrix using a CVD process, the colour of the coatings changed from brown-yellow to a more acceptable blue; the hue and intensity of the colour depended on both concentration and dimension/shape on the NPs. Moreover, a T_c value of 52 ^{o}C was observed.

Higher Transmittance in the Visible

An effective way to improve transmittance in the visible is with the use of multi-layer systems; for instance, a multi-layer stack made of $TiO_2/VO_2/TiO_2$ coatings has a visible transmittance about 30 % higher than the simple VO_2 coating.[3] This behaviour is due to the complex interference mechanisms taking place between the different coatings, due to their different optical properties.

The Way Forward

The development of Solar Control Coatings already proved to be an effective way to reduce energy consumption; the existence of commercial products confirms this. Further improvements can be achieved with the development of more advanced materials, VO_2 being an example. To achieve this, more research has to be carried out, to optimise the behaviour of the coatings, creating smart optical SSC materials, leading to higher energy savings. This shows how the study of the interactions between light and matter is an essential part of our progress towards a more sustainable future.

References

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