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Smart Materials as Intelligent Insulation

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Introduction

What are smart dielectrics?

➢Smart dielectrics are materials which contain a functional chemical group which produces a measurable response dependant on environmental changes. For example, electric field sensitive fluorophores can be designed and introduced into the dielectric such that changes in fluorescent properties are indicative of the local electrical environment or dielectric degradation. Such materials can be tailored to the desired application.

Benefits and potential applications

➢Smart dielectrics provide a means of continual condition assessment of electrical plant which is non invasive, easily interpreted and inexpensive to maintain. An exemplar application would be the use of smart dielectrics to remotely monitor the presence of charge on gas insulated switchgear (GIS) spacers. Other uses in outdoor insulation systems to detect the presence of an electric field or as a means of dielectric condition assessment can be envisaged.

Considerations for Material

Requirements of material;

➢Responsive to local electrical environment changes, preferably reversibly.

➢Clear output which can be readily interpreted (e.g. a distinct colour change, fluorescence or change in opacity).

➢Introduction of smart moiety must have minimal effect on electrical properties of bulk material

➢Smart moiety functional group would ideally be cheap to synthesize and easy to introduce into the bulk polymer.

Fluorophores

Directly-doped pyrene blends

➢Fluorophores are well know to be influenced by their surrounding in terms of solvents. We decided to investigate if fluorophores were also electrical field sensitive.

➢Pyrene was dissolved into a solution of polystyrene, samples were then oven dried for 3 hours at 40 °C. Serial dilutions of a stock pyrene solution allowed for concentrations of pyrene as low as 0.0001 %wt.

➢All samples showed strong fluorescence under a UV lamp (254 nm).

➢Introduction of pyrene into a host polystyrene matrix resulted in minimal changes in dielectric strength, even for the 5 % pyrene blend, which had the same eta value of 161 kV mm^{-1} as virgin PS.

Fig. 1. Comparison between polystyrene doped with pyrene (5%wt.) and unmodified polystyrene.

➢The fluorescence spectrum of pyrene was altered dramatically when blended into a polymer and it was felt that any field dependence would be eclipsed by host-polymer effects.

Chromophores

Polarisation of Chromophores

➢Fluorophores were found in general to be too sensitive to the host polymer, raising concern that any electrical field sensitivity would be eclipsed by effects from the local polymer environment.

➢Chromophores such as azo dyes were thought to be a more practical replacement of fluorophores. Disperse red 1 (fig. 2) was chosen for initial investigations as electrical field sensitivity of this molecule is already documented.

➢Previous work uses corona techniques to polarise DR1 molecules within a sample. In this method, a high electric field at a needle point causes ion formation. These ions are then “sprayed” onto the surface of the sample. A clear colour change from red to purple was reported during polarisation.

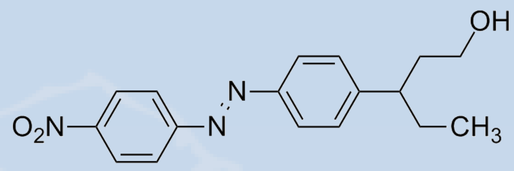

Fig. 2. Chemical structure of Disperse Red 1 (DR1)

➢As an alternative method of polarisation, samples of DR1 doped polymers were pressed into 100 µm discs and held between ring and mushroom electrodes. This produces a more uniform electric field compared to corona. A spectrograph measures any small colour changes during polarisation (fig. 3).

➢Initial results suggest that electrochemical reactions on the surface of the doped polymer may account for the colour changes reported in the literature.

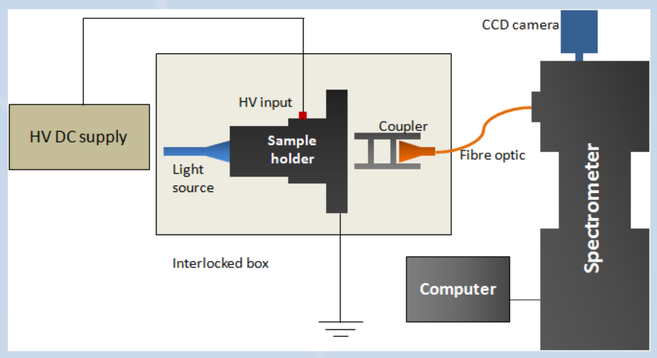

Fig. 3. Schematic of polarisation experiment used to obtain real time spectral information whilst the sample is under electrical stress.

Liquid Crystals

The liquid crystal state

$$T_m < T < T_c$$

T_m: temperature at which the material melts from a solid to a mesophase

T: temperature region where a liquid crystalline state is formed

T_c: clearing temperature when LC transforms into an isotropic liquid

$<T_m$ long range positional and orientation order. SOLID

Long range orientation order only. LIQUID CRYSTAL

$>T_c$ no long range order at all. ISOTROPIC LIQUID

➢LC materials can contain polar or non-polar molecules,

- Polar molecules posses *permanent dipole moments.*
- In non-polar molecules *induced electric dipoles* are created when and electric field is applied (much weaker than permanent dipoles).

➢LC molecules can posses permanent or induced dipoles either along or across the length of the molecular axis.

➢Application of an electric field can cause reorientation of the director **n** (the average direction in which molecules align in a particular region or domain).

Polymer Dispersed Liquid Crystals

Smart Glass

➢Smart glass often consists of a polymer dispersed liquid crystal layer (fig. 4) which changes transparency on applications of an electrical field.

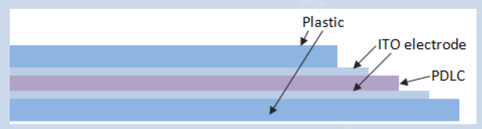

Fig. 4. Schematic showing the different layers in a sample of MagicGlas™ (not to scale).

➢A sample of MagicGlas™ Switchable Film was provided by Glasnovations. The film is commonly used in modern architecture where switchable privacy screening is necessary such as hospitals and meeting rooms.

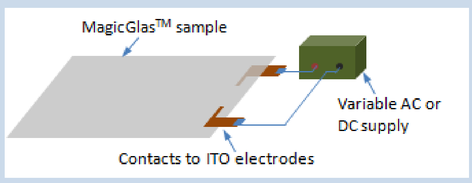

Fig. 5. MagicGlas samples connected to either an AC or DC supply shows switching to the transparent state at approximately 60 V.

➢Under normal operating conditions (fig. 5), when the MagicGlas™ film is in an ‘OFF’ state, the liquid crystal within the PDLC has many different domains, each with differently orientated directors. Light is scattered in every direction, giving the film a white opaque appearance. When the film is switched ‘ON’, a uniform electrical field is produced across the PDLC layer causing alignment of directors. This means that light is no longer randomly scattered, and the film appears transparent.

➢As the change in transparency is a response to an electrical field across the PDLC layer of the film, it is anticipated that the presence of a sufficiently high electrical field should cause a change in opacity, even when the film is not connected to a power supply as in fig. 6.

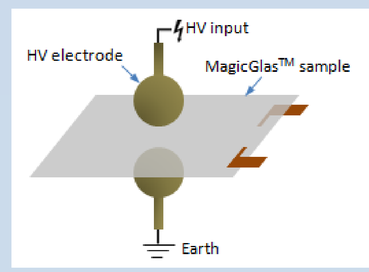

Fig. 6. Experiment to test MagicGlas film in a high voltage electrical field.