An Application of Electrorheological Fluids to Smart Windows*

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Abstract Electrorheological fluids (ER fluids) are typical non-aqueous suspension consisting of dielectric particles dispersed in non-conducting fluids, which show a reversible viscosity increase upon application of an external electric field. According to the obvious changes of the transmittance of ER fluids under an applied electric field, an assumption on the application of ER fluids to smart windows is presented in this paper. Applying and removing an electric field of 500 V·mm^{-1}, a reversible solar transmittance change as much as 42.0% at the wavelength of 500 nm is experimentally obtained.

Key words electrorheological fluids; smart window; transmittance; transmission spectra

The influence of an electric field on the deformation and the flow properties of materials has been a subject of much interest for a long time. It was Winslow who first reported the observation of a large induced electrorheological(ER) effect in 1947, which sometimes is referred to as the "Winslow effect"[1] . More recently, the ER effect has attracted renewed attention especially in the USA, the UK, Japan and Germany. An electrorheological fluid (ER fluid) that is traditionally identified as suspension of dielectric powders or polymeric particles (the dispersing phase) in an insulating oil (the continuous medium) is of potential application in a wide variety of systems such as engine mountings, isolation systems and power controlled devices, which take advantages of the fluids' continuously variable viscosity controlled by the application of an electric field[2].

From the viewpoints of environmental issues, saving energy has become increasingly important. An electrochromic smart window (ECSW) is thought to be more effective for electrically controlled absorption because of the large transmittance change about 40%[3]. An ECSW is, however, seriously limited in size as a result of its operating electric current. On the other hand, a dilute ER fluid is believed to be superior for smart windows[4]. In the first of a series of papers, the ER fluids-based smart window (ERFSW) with the suspension of silica particles in silicone oil is developed, which forms particle chains under an external electric field. In addition, its optical properties with an emphasis on electrically controlled transmittance are also investigated.

1 Experiment

1.1 Materials and Sample Preparation

The ER fluids which are suspensions of silica particles dispersed in silicone oil were prepared for use. The dispersing phase was silica particles with an average diameter of 0.5 μm, which were treated by means of traditional process for ceramics. Namely, it was sintered at the temperature of 1 200℃ for 2 hours, ball-ground for 12 hours and sieved. The continuous medium is silicone oil with Newtonian viscosity at room temperature of 250 cst. Before used, the silicone oil was boiled at least 15 min to remove the involved water and then cooled in a dryer. With no stabilizer or enhancing reagents introduced to ERF, the ready-made silica particles were dispersed in silicone oil at the particle concentration of 1.5 wt%, 2.0 wt%, 2.5 wt% with the aid of an ultrasonic disperser and labeled as S_1, S_2, S_3, respectively.

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1.2 Smart Window Cell Preparation and Performance Evaluation

In order to fabricate an ERFSW cell, the above resulting ERF were sandwiched between a pair of ITO electrodes mounted with 2mm-sized spacers, whose performance can be assessed by solar transmittance $T(\lambda)$ at a wavelength of λ defined as

$$T(\lambda) = \frac{I(\lambda)}{I_0(\lambda)} \times 100\% \quad (1)$$

where, $I(\lambda)$ is the intensity of the transmission solar and $I_0(\lambda)$ is the intensity of the incident solar at the wavelength of λ. Without and with an electric field applied, the change of solar transmittanse at the wavelength of λ can be defined as

$$\Delta T(\%) = T_{on}(\%) - T_{off}(\%) \quad (2)$$

where T_{on} or T_{off} is the solar transmittance with or without an electric field applied, respectively.

The transmission spectra of the cell were measured over the wavelength between 300 nm and 2 000 nm using a set of UV -365 spectrophotometer and the effect of the electric field strength on the transmittance was investigated by means of F7320 spectrophotometer at the wavelength of 570 nm.

2 Results and Discussions

2.1 Schematic Illustration of ERFSW

Fig. 1 shows the schematic illustration of the ERFSW cell. Silica particles in the ER fluid were moving randomly by the Brownnian motion and evenly suspending in silicone oil in the absence of an electric field. In this state, the cell exhibits low solar transmittance mostly due to the absorption and dissipation for light by the ER fluid in the cell. However, on the application of an electric field with enough strength, it is generally accepted that each particle in the ER fluid acquires induced dipole[5], as a result, the dipole-dipole interactions cause chain-like structure of particles (particle chains) in the direction parallel to the electric field vector, resulting in a higher solar transmittance. When the electric field was removed, the particle chains were broken up and the particles were simultaneously returned to the original random state by the thermal motion.

2.2 Effect of Applied Electric Field Strength

Fig. 2 shows the solar transmittance of ERFSW cell against the applied dc electric field strength. Suspension S_2 performs much stronger ER effect than the others with the increase of electric field strength. And the dispersed particle chains become more and more ordered, as well, the increase in solar transmittance resulted from the passages for light between the particle chains. The columns or networks constructed gradually of a collection of many particle chains leads to the decrease in solar transmittance under an strong electric field. Meanwhile, in an ER fluid with low particle concentration, particle chains are difficultly developed resulting in more scattered light from suspending particles, by contrast, branching chains or networks are easily formed, both of which is responsible for low solar transmittance change. It was experimentally implied that the ER effect strongly depends on the particles concentration of the ER fluid,

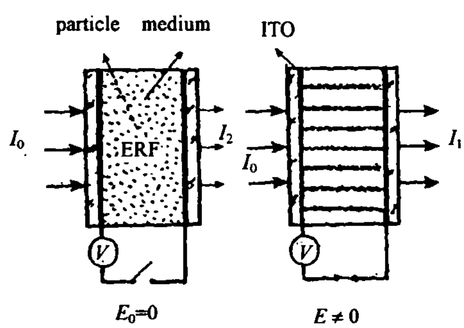

Fig.1 principle for the ERFSW cell, left state without electric field, right state with electric field.

and clearly indicated that the ER fluid with the particle concentration of 2.0 wt% exhibits wonderful ER response.

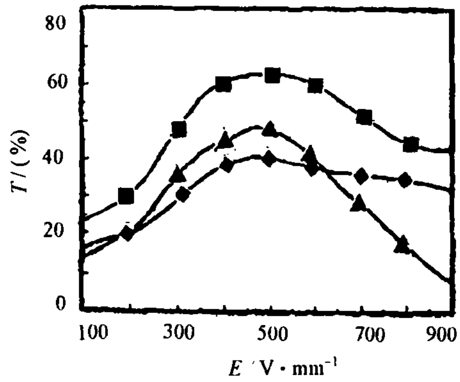

Fig. 2 Solar transmittance versus the electric field strength at different particle concentration

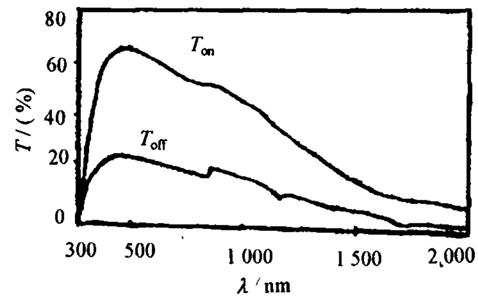

Fig. 3 The transmission spectra of the ER fluid-based smart window cell

2.3 Transmission Spectra of ERFSW

Fig. 3 shows the transmission spectra of the ERFSW cell consisting of S_2, which was measured between 300 nm and 2 000 nm in the presence and absence of the dc electric field of 500 V • mm^{-1}. The solar transmittance in both state is 67.0% and 25.0%, respectively. The solar transmittance change at the wavelength of 500 nm is 42.0%, which is larger than that of the ECSW. As a result, the ERFSW are with the characteristics of electrically induced transmittance enhancement between visible band and near-infrared band.

3 Conclusions

In summary, the solar transmittance change of about 42.0% was obtained with the ERFSW cell using the suspension silica particles in silicone oil. The remarkable transmittance change resulted from the high absorption and dissipation for light of the ER fluids and a sharp decrease of the ER fluids absorbing light due to the formation of the particle chains without and with an electric field applied, respectively. More in-depth chemical and physical investigations will be conducted in order to fully understand the nature of the ERFSW and improve the solar transmittance change. It is believed that the ERFSW seem to be a promising device applicable to the switchable light control of high durability and performance with the materials explored.

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电流变液在灵巧窗中的应用*

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【摘要】 电流变液是介电颗粒分散于非导电性液体中而成的典型非水悬浮体，在外加电场作用下，具有粘度增大的可逆特性。由于电流变液在外加电场下具有透射率的明显变化，文中提出了电流变液应用于灵巧窗的设想。结果表明，在波长500 nm下，外加强度为500· V.mm^{-1}的电场前后，电流变液灵巧窗可逆透射率变化可达42.0%.

关 键 词 电流变液；灵巧窗；透射率；透射率频谱

中图分类号 TB39

• 科研成果介绍 •

8 mm 频率综合器

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该项成果采用对8 mm频率的基波锁相方法，自行研制了一个高稳定的2.61 GHz ~3.96 GHz的低相噪微波参考源，利用谐波混频，直接锁定8 mmYTO。完成了频率范围为26.5 GHz ~40 GHz，步进分辨率为1 MHz的频率综合器样机。控制软件采用了高精度频率预置，线性补偿和模拟消磁程序。

高温超导材料探测分析机理

主研人员 宁永功 谢 红 秦会斌等

该项目揭示了高温超导薄膜的宏观性能与薄膜表面界面状态，微结构状态的关系，明确影响高温超导材料性能的有关因素，为加速超导薄膜的制备、器件的研究提供了有效的依据和方法。用低能量，低密度离子束作表面处理，可提高T_{co}达1 K ~3.3 K。这一新技术可广泛用于超导微波器件、红外探测器、超导结加工等方面。用XRO摇摆曲线，对单晶基片质量作无损检测。此外，还可扩展应用到其他领域中，如各种单晶片的质量检测，多晶取向膜分析和各种薄膜表面、界面分析等。

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