DETERMINATION OF THE OPTICAL CONSTANTS OF THE ACTIVE LAYER OF A SUSPENDED PARTICLE DEVICE SMART WINDOW WITH MULTILAYER STRUCTURE, AT THE CLEAR AND DARK STATES, WITH AND WITHOUT APPLIED VOLTAGE.

0 V_{peak}~

David BARRIOS [1, 2]*, Carlos ÁLVAREZ [1], and Gunnar A. NIKLASSON[3]

1 Universidad Politécnica Salesiana de Guayaquil, Ecuador

2 Grupo de Displays y Aplicaciones Fotónicas, Universidad Carlos III de Madrid, C/Butarque 15, E-28911 Leganés, Madrid, Spain

3 Department of Engineering Sciences, The Ångstrom Laboratory, Uppsala University, P.O. Box 534, SE-75121 Uppsala, Sweden

*Corresponding author: dbarrios@ups.edu.ec

UNIVERSIDAD POLITÉCNICA SALESIANA ECUADOR

UPPSALA UNIVERSITET

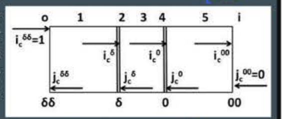
10 V_{peak}~

Sandwich structure of the SPD including two glass substrates (1,5) and two ITO thin films (2,4) surrounding the inner SPD active layer (3).

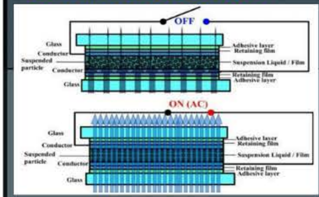
ABSTRACT

Smart windows based on suspended particle devices (SPDs) are able to switch optically from dark to clear visual appearance when applying an AC electrical signal. This effect is due to light absorbing nanoparticles that get aligned by the applied voltage. The sandwich structure of a SPD consist of several layers and includes two outer glass substrates, each one covered on its inwards-facing side with a transparent conducting thin layer surrounding the centrally positioned SPD active layer. A knowledge of the optical constants of each layer—*i.e.*, the complex refractive index, including its real and imaginary (absorption and scattering) parts—is a key in the design of the visual appearance of the SPD window and is a useful tool to determine the optimum thickness of the active layer.

20 V_{peak}~



1. INTRODUCTION



2. EXPERIMENTS

SPD smart window in dark (left) and clear (right) states with 0 and 100 V_{peak} applied.

2.1 Devices

30 V_{peak}~

A SPD sample with 28 x 22 cm² active area and 1 cm total thickness was supplied by CRICURSA (Cristales Curvados S.A., Barcelona, Spain), which is a licensee of Research Frontiers Inc. (Woodbury, NY, USA). The inner active layer consists of a cross-linked polymer matrix containing droplets comprising a suspension of polyhalide particles [1-2]. The SPD sample operated with 0 (dark state) and 100 V_{peak} (clear state) sinusoidal signals.

2.2 Optical measurements

40 V_{peak}~

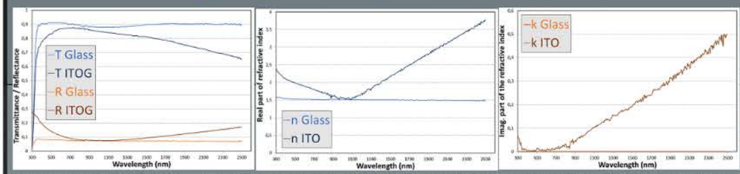
A Perkin Elmer Lambda 900 spectrophotometer, equipped with an integrating sphere, was used for measuring the total and diffuse transmittance and reflectance (*T* & *R*) of the SPD sample in the solar wavelength range (200 to 2500 nm) in steps of 5 nm.

Two samples, an uncoated glass and a glass covered with ITO, were optically characterized. The complex refractive index of the glass sample (n^G and k^G) was derived from measurements ($T_{dir}{}^G$ and $R_{spec}{}^G$) by collimated-collimated (cc) equations of the four-flux model, which are appropriate for a thick slab of material [3, 5].

50 V_{peak}~

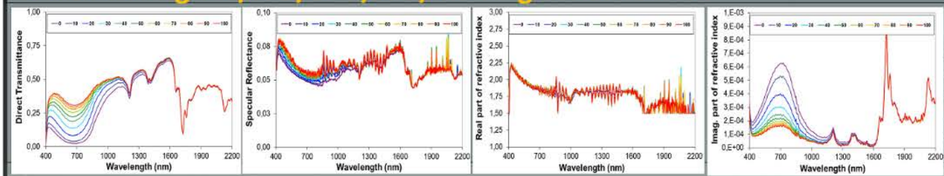
3. RESULTS

3.1 Glass and glass/ITO samples



For the ITO-glass sample, the Pfrommer model [4] was used with an electric field matrix for the thin layer, which takes into account interference effects. Optical constants of ITO (n^{ITO} & k^{ITO}) were derived from measurements of $T_{dir}{}^{ITOG}$ and $R_{spec}{}^{ITOG}$ once optical constants of glass had been computed from measurements of $T_{dir}{}^G$ and $R_{spec}{}^G$.

3.2 Outside glass/ITO/SPD/ITO/inside glass sandwich



60 V_{peak}~

In order to derive optical constants of the SPD layer, the whole five-layer stack was modelled by the multilayer film optics model of Pfrommer et al. [4]. The thick layers (glass and SPD) were treated by considering propagation of light intensities while for the thin ITO layers interference effects were included.

Intermediate T values for 10, 20, 30, 40, 50, 60, 70, 80, and 90 V_{peak} were also measured.

70 V_{peak}~

$$R_{xx} = R_0 + \left(R_{100} - R_0\right)\cdot\frac{\left(T_{xx} - T_0\right)}{\left(T_{100} - T_0\right)}$$

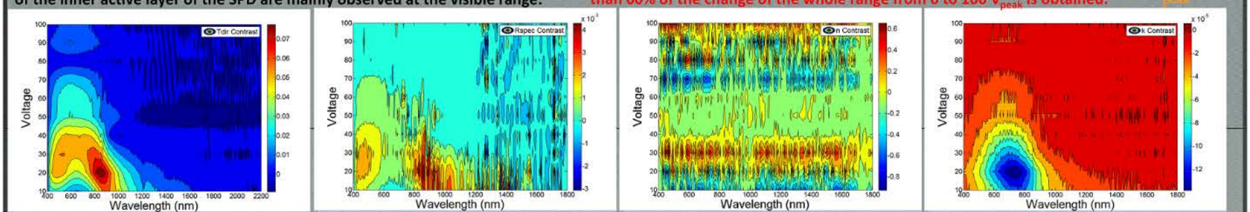
Assuming that the different orientations of dispersed particles for each voltage level cause the different spectral intermediate values of T, intermediate values of R should be related to intermediate values of T and therefore can be estimated. Equation proposed for estimating intermediate values of R_{tot} and R_{diff}, and hence R_{spec}, from intermediate values of T_{tot} and T_{diff}, being xx from 10 to 90 V_{peak} applied:

4 CONCLUSIONS AND FUTURE WORK

Voltage steps dependence with spectral T_{dir}, R_{spec} and imaginary refractive index k of the inner active layer of the SPD are mainly observed at the visible range:

Contour plots showed that, for the first four steps from 0 to 40 V_{peak}, more than 60% of the change of the whole range from 0 to 100 V_{peak} is obtained.

80 V_{peak}~



Herapathite, which is similar to the particle material of the SPD's active layer (numbered "3" in the schematic sandwich structure), is an artificial polyiodide crystal (with refractive index around 1.6) showing extraordinary dichroism so that light rays with different polarizations are absorbed to different amounts [6].

5 ACKNOWLEDGMENTS

90 V_{peak}~

We are grateful to CIDETEC for providing the SPD window, the glass and ITO-Glass samples.

IK4 CIDETEC

March 5th-9th, 2018, College Station, Texas, USA

National Aeronautics and Space Administration, Goddard Institute for Space Studies

6 REFERENCES

[1] D. Barrios, R. Vergaz, J. M. Sanchez-Pena, B. Garcia-Camara, C. G. Granqvist, G. A. Niklasson, *Thickness dependence simulations of the optical properties for a suspended particle device derived from scattering and absorption coefficients*. Solar Energy Materials and Solar Cells 143: 613- 622 (2015).

[2] D. Barrios, R. Vergaz, J. M. Sanchez-Pena, C. G. Granqvist, G. A. Niklasson, *Toward a quantitative model for suspended particle devices: optical scattering and absorption coefficients*. Solar Energy Materials and Solar Cells 111: 115 -122 (2013).

[3] B. Maheu, JN. Letoulouzan, G. Gouesbet. *Four-flux models to solve the scattering transfer equation in terms of Lorenz-Mie parameters*. Applied Optics 23: 3353-3362 (1984).

[4] P. Pfrommer, K. J. Lomas, C. Seale, C. Kupke, *The radiation transfer through coated and tinted glazing*. Solar Energy 54, 287-299 (1995).

[5] R. C. McPhedran, L. C. Botten, D. R. McKenzie, R. P. Netterfield, *Unambiguous determination of optical constants of absorbing films by reflectance and transmittance measurements*. Applied Optics 23: 1197-1205 (1984).

[6] C. D. West, *Cristallographie of herapathite*. American Mineralogist 22: 731-735 (1937).

100 V_{peak}~