# Optical properties of selectively absorbing C/NiO nanocomposite coatings

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## INTRODUCTION

Nanocomposite thin films are widely used for solar thermal applications [1]. Using carbon nanoparticle containing metal oxide as a spectrally selective solar absorber coating has grown significantly in recent years [2-5]. Recently, Katumba *et al*. [3,4] have compared carbon embedded in three different metal oxides ($SiO_2$, ZnO, and NiO) and deposited on aluminium substrate using a sol-gel technique. Some of the advantages of this novel technique to fabricate carbon-metal oxide composite coatings are that it is simple and easy to control, the coatings can be deposited at ambient pressure conditions, and the process is low in material consumption. Therefore, the method is very promising and could hopefully reduce the production costs for spectrally selective absorbers. According to Katumba *et al.* [3,4], among the three carbon/metal oxide composite materials, carbon in NiO matrix has shown superior optical properties. Although the feasibility of the C/NiO composite coatings for a selective solar absorber application has been published, a detailed systematic investigation on the effect of the sol-gel fabrication process parameters on the structural and optical properties as well as the optimized theoretical design were not reported. It is therefore the purpose of this work to theoretically optimize the C/NiO composite coatings.

### Fundamentals

The power density ,P, of thermal radiation emitted by a black body of temperature T is

$P = \sigma T^4$, $\sigma = 5.67 \times 10^{-8}$ W/m²K⁴ (1)
(Stefan-Boltzmann law)

Kirchhoff's Law: $\alpha(\lambda) = \varepsilon(\lambda) = 1-R(\lambda)$ (Opaque surface)

$$\alpha_{sol} = \frac{\int_{0.3}^{2.5} I_{sol}(\lambda)(1-R(\lambda))\,d\lambda}{\int_{0.3}^{2.5} I_{sol}(\lambda)\,d\lambda} \quad (2);\quad \varepsilon_{therm} = \frac{\int_{2.5}^{20} \rho(\lambda)(1-R(\lambda))\,d\lambda}{\int_{2.5}^{20} \rho(\lambda)\,d\lambda} \quad (3)$$

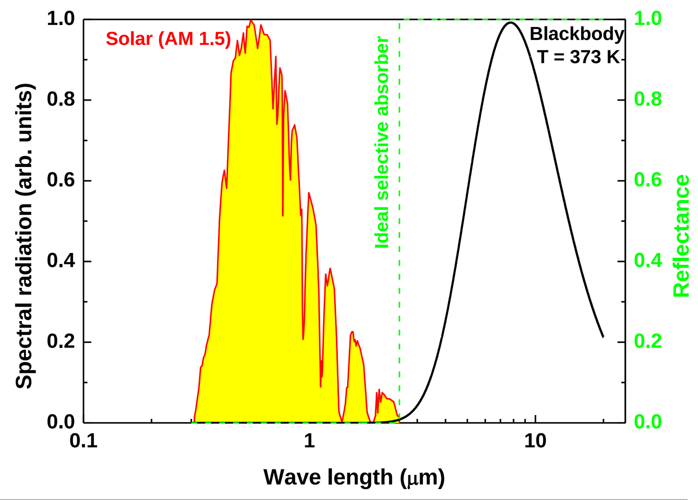


Fig.1. Solar radiation AM 1.5, black body radiation at 100 °C and reflection of an ideal optically selective coatings

At T = 80 °C, from eq. (1), P ~ 900 W/m² ~ incident solar energy at the ground
→ An optically selected surface is required

### Aim

An attempt is made to theoretical lymodel the optical properties of the composite layer that are required to obtain optimized C/NiO absorbers,

## Theoretical approach

The two most widely used theories for the determination of the optical constants of the composite coatings are : Maxwell Garnett (MG) [6], and Bruggeman (Br) [7].

$$\overline{\varepsilon^{MG}} = \varepsilon_B \frac{\varepsilon_A + 2\varepsilon_B + 2 f_A(\varepsilon_A - \varepsilon_B)}{\varepsilon_A + 2\varepsilon_B - f_A(\varepsilon_A - \varepsilon_B)} \quad (4) \qquad f_A \frac{\varepsilon_A - \overline{\varepsilon^{Br}}}{\varepsilon_A + 2\overline{\varepsilon^{Br}}} + (1-f_A)\frac{\varepsilon_B - \overline{\varepsilon^{Br}}}{\varepsilon_B + 2\overline{\varepsilon^{Br}}} = 0 \quad (5)$$

The matrix form for a single layer [8]:

$$\begin{bmatrix} 1 \\ n_0 \end{bmatrix} + \begin{bmatrix} 1 \\ -n_0 \end{bmatrix} r = M \begin{bmatrix} 1 \\ n_T \end{bmatrix} t \quad (6)$$

$$M = \begin{bmatrix} \cos kl & -\frac{i}{n_1}\sin kl \\ -in_1 \sin kl & \cos kl \end{bmatrix} \quad ; \quad k = \frac{2\pi}{\lambda} = \frac{2\pi n_1}{\lambda_0}$$

For a multiple layer:

$$M_1 M_2 M_3 \cdots M_N = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \quad (7)$$

$$r = \frac{An_0 + Bn_T n_0 - C - Dn_T}{An_0 + Bn_T n_0 + C + Dn_T} \longrightarrow R = |r|^2$$

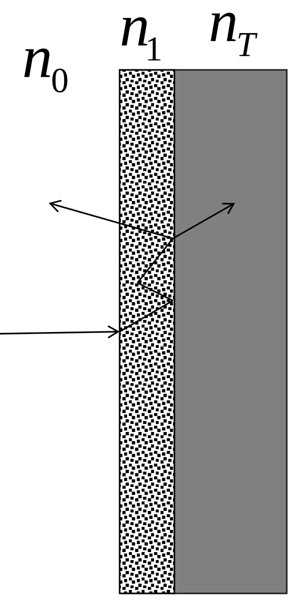


Fig. 2. Schematic representation of the multilayer structure used in this study

## Results

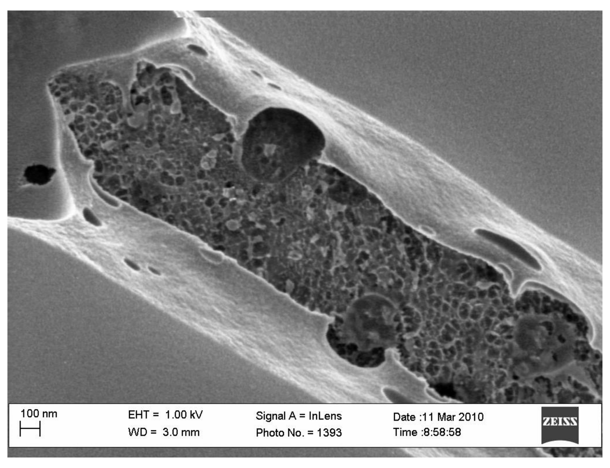

Fig. 3. SEM image of a typical C/NiO nanocomposite coating

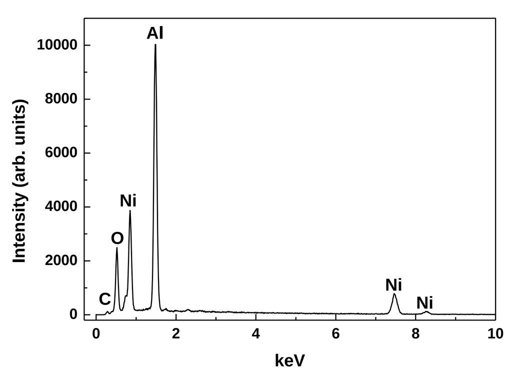


Fig. 4. Typical EDS spectrum for C/NiO composite coating

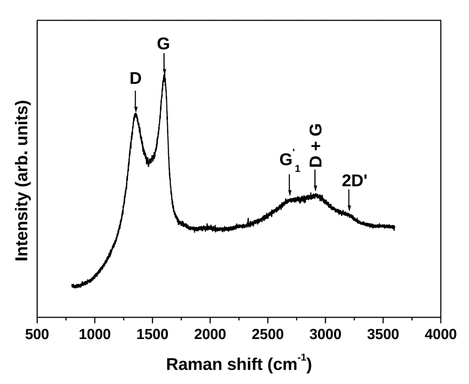


Fig. 5. Raman spectrum for a typical C/NiO composite coating

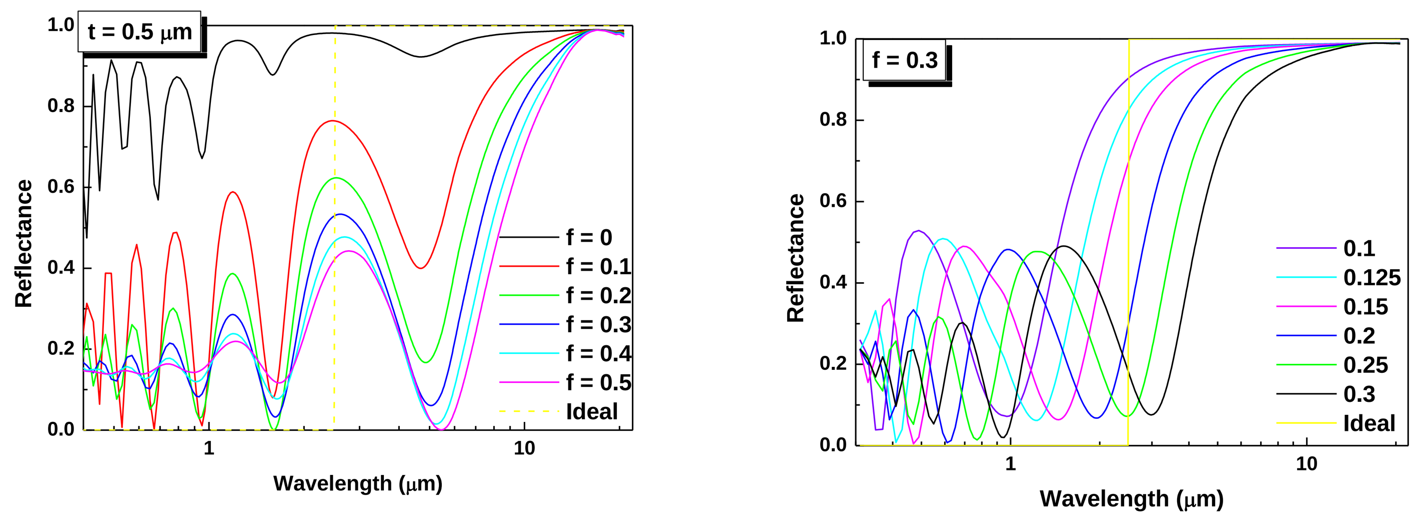


Fig. 6. Reflectance spectra for C/NiO composites obtained from calculations based on the Maxwell Garnett effective medium theory

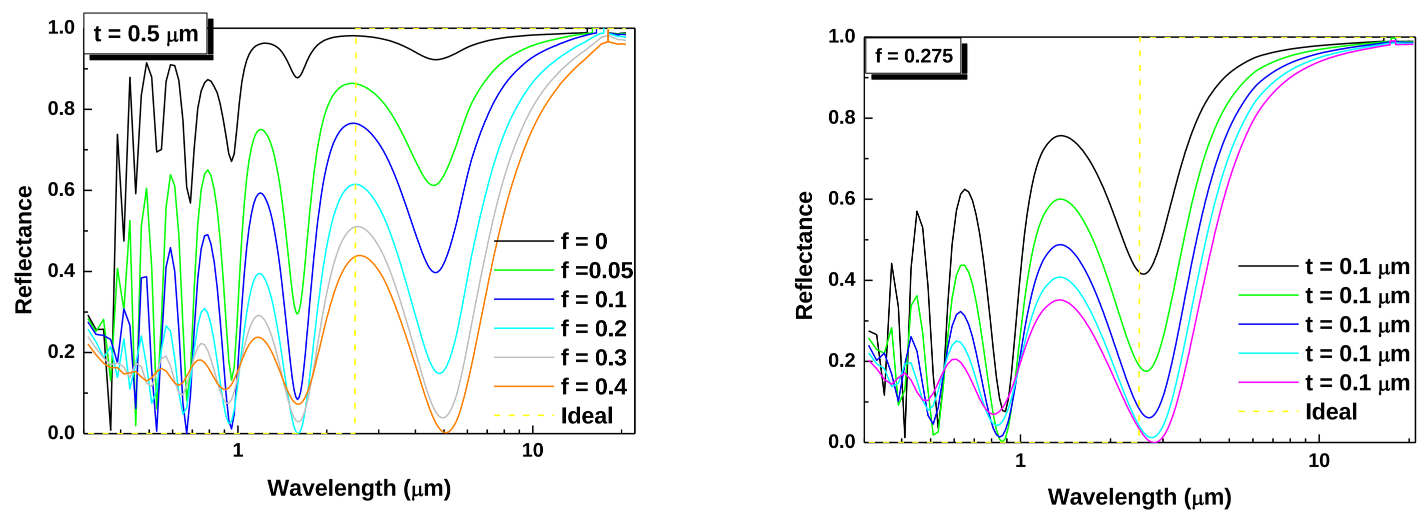


Fig. 7. Reflectance spectra for C/NiO composites obtained from calculations based on the Bruggman effective medium theory

### Comparison with experiment

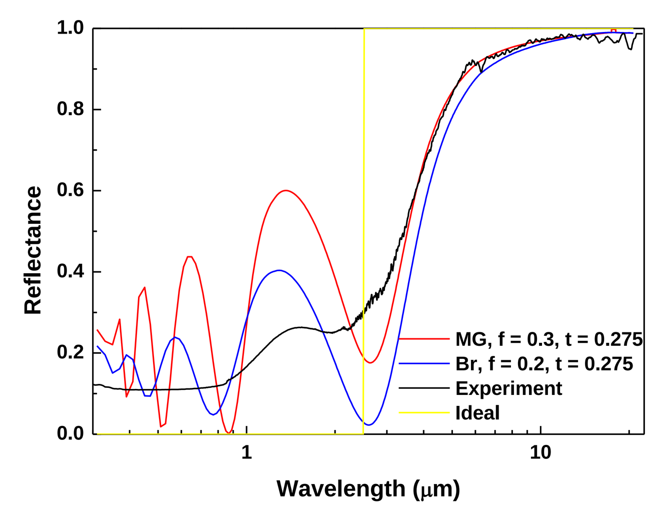


Fig. 8. Reflectance spectra for C/NiO composites obtained from calculations based on the Maxwell Garnett and Bruggeman effective medium theory compared with experiment

## Conclusions

❖ The Maxwell Garnett and Bruggeman effective medium theories have been used to model the optical properties of C/NiO composite coatings.

❖The theory agrees reasonably well with the experiment except in the solar range.

❖The possible explanation for the disparity in the reflectance might be the multiple scattering in the pores of the coatings and roughness of the substrate which has not been accounted in the theory.

❖ The theory assumes that the composites are treated as a homogeneous layer with perfectly smooth interfaces, which could be the reason for the disappearance of the interference pattern in the coatings.

❖ Further simulation is necessary in order to address the disparity between theory and experiment.

## References

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