บทความวิจัย

สมบัติทางแสงของกระจกสะท้อนความร้อนที่มีเงินอัลลอยด์เป็นชั้นหลักด้วยวิธีจำลองแบบ
Optical Property of Ag-alloy Based Heat Reflection Mirror by Simulation Technique

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บทคัดย่อ

ฟิล์มบางเงินมีสมบัติทางแสงที่ดีเหมาะสำหรับเป็นชั้นสะท้อนอินฟราเรดของกระจกสะท้อนความร้อนที่มีโครงสร้างแบบ $TiO_2/Ag/TiO_2$ อย่างไรก็ดีฟิล์มบางเงินเสื่อมสภาพได้ง่ายเมื่อสัมผัสแก๊สออกซิเจนในระหว่างการเคลือบ ปัญหานี้แก้ได้โดยใช้เงินอัลลอยด์แทนเงินบริสุทธิ์ บทความนี้เป็นรายงานการศึกษาความเป็นไปได้ในการใช้ฟิล์มบางเงินอัลลอยด์เป็นชั้นสะท้อนอินฟราเรดของกระจกสะท้อนความร้อน โดยเคลือบฟิล์มบางเงินอัลลอยด์และฟิล์มบางไททาเนียมไดออกไซด์ ที่มีความหนาเท่ากับ 30 nm บนกระจกสไลด์ด้วยระบบดีซีแมกนีตรอนสปัตเตอริง เพื่อใช้หาค่าคงที่ทางแสง (n และ k) ด้วยโปรแกรม TFCalc ซึ่งเป็นโปรแกรมสำหรับออกแบบฟิล์มบางแสง พบว่าที่ความยาวคลื่นแสงเท่ากับ 500 nm ฟิล์มบางเงินอัลลอยด์มีค่า n= 0.05 และ k = 2.92 ขณะที่ฟิล์มบางไททาเนียมไดออกไซด์มีค่า n= 2.38 และ k = 0 โดยค่าการส่งผ่านแสงจากการจำลองแบบด้วยโปรแกรม TFCalc เมื่อแปรค่าความหนาชั้นเงินอัลลอยด์ของกระจกสะท้อนความร้อนที่มีโครงสร้างแบบ TiO_2(30 nm) / Ag-alloy(x) / TiO_2(30 nm) สรุปได้ว่าฟิล์มบางเงินอัลลอยด์มีศักยภาพที่จะนำมาใช้เป็นชั้นสะท้อนอินฟราเรดของกระจกสะท้อนความร้อนได้

คำสำคัญ : กระจกสะท้อนความร้อน ฟิล์มบาง แมกนีตรอนสปัตเตอริง เงินอัลลอยด์ ไททาเนียมไดออกไซด์

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Abstract

Silver thin films possess many excellent optical properties; it is suitable for use to be an IR-reflected layer of heat reflection mirror with $TiO_2/Ag/TiO_2$ structure. However, it easily degrades when exposed to oxygen gas during the deposition sequence. This problem may be solved by using Ag-alloy instead of pure Ag. This paper presents the results of the feasibility study to use Ag-alloy thin film as an IR-reflected layer of heat reflection mirror. Thin films of Ag-alloy and TiO_2 thin film with a thickness of 30 nm were deposited on slide glasses by DC magnetron sputtering. The optical constants (*n* and *k*) of Ag-alloy and TiO_2 thin films were evaluated by TFCalc, the optical thin films design software. The optical constant of Ag-alloy thin film, at 500 nm, are $n= 0.05$ and $k = 2.92$ while TiO_2 thin film are $n= 2.38$ and $k = 0$. The simulated results of the transmittance from TFCalc, that varies with the thickness of Ag-alloy layer of heat reflection mirror with TiO_2(30 nm) / Ag-alloy(x) / TiO_2(30 nm) structure, it can be concluded that Ag-alloy thin film could potentially serve as an IR-reflected layer of the heat reflection mirror.

Keywords : Heat Mirror, Thin Film, Magnetron Sputtering, Ag-alloy, Titanium Dioxide

Introduction

There were two technology innovations involved in flat glass industry and its related products in the 20th century. One is the flat glass production technology, and the other is the large-area coating technology. Recently, coated glass products for special purposes such as spectrally selective glazing, solar control, low-E (low emissivity glass) are very popular. One of these special coating is the silver-based low-E coating, which has been extensively studied for more than 10 years, which are widely used for an energy-efficient window such as insulating glass units or solar control or heat reflection mirror, because of their high performance on thermal insulation[1-4]. The basic layer systems of these coatings are composed of the optical multilayer thin films of suitable materials with specified design. Now, in view of the growing energy crises, there is wide spread interest over the world for higher performance products, especially those that could contribute to energy savings [3,5].

An energy-efficient window is a device capable of providing lighting and thermal comfort at minimum paid of energy for air-conditioning. The solar spectrum is roughly split between the visible and the near-infrared regions. When overheating from excessive solar input is a problem, one can obtain energy efficiency by using multilayer thin film-coated glass windows called heat mirrors that are transparent for visible light and reflecting for infrared (IR) solar radiation. A three-layer system of Dielectric/Metal/Dielectric (D/M/D) or Dielectric/Alloy/Dielectric (D/A/D) on a glass substrate could be use as a spectrally selective filter that reflects IR radiation and transmits most of the visible spectrum. The highly reflective metal film or alloy film (that would otherwise be opaque to the visible light) is sandwiched between the two dielectric layers that act as antireflection coatings for the visible thus increasing the visible transmission. By varying the material and thickness of the three layers, the optical properties of the D/M/D or D/A/D films can be tailored for suit different applications.

Spectrally selective glazing or heat reflection mirrors have been constructed by forming of D/M/D layers on glass substrates. For example, $TiO_2/Ag/TiO_2$[6-10]

and tin doped indium oxide, coatings on glass have been used to fabricate heat mirrors that are energy efficient window.

Ag thin films possess many excellent optical properties; it is suitable for use to be an IR-reflected layer of heat reflection mirror with D/M/D structure. However, it easily degrades when exposed to O2 during the oxides layer deposition sequence. This problem may be solved by using Ag-alloy in which Ag is doped with Pt, Pd or Cu instead of pure Ag [11].

Performance of the heat reflection mirror of both D/M/D and D/A/D structure depends critically on the optical constants and thicknesses of the Ag alloy and the metal oxide films used. Oxide coatings depend heavily upon stoichiometry, impurities and defects in the films [10]. Metal or alloy films are very dependent upon nucleation and coalescence phenomena.

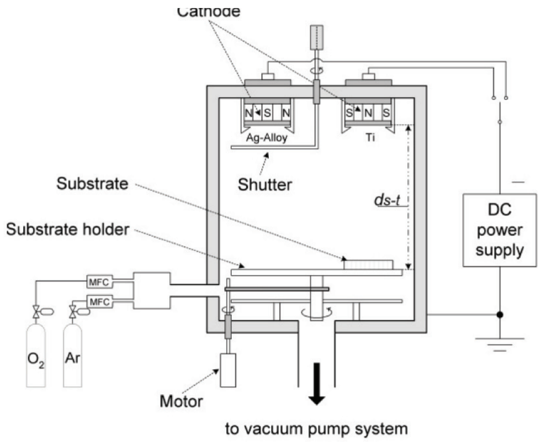
In all films the degree of crystallinity, crystal structure and impurities influence optical conductivity. It is common knowledge, however, that thin films produced by a similar process in different laboratories, or indeed, in different deposition systems of the same laboratory, have different optical constants. This is because different geometry and conditions give rise to different thin film structures and composition. Thus, before a multilayer device, heat reflection mirror, is fabricated, it follows from above that, knowledge of the optical properties of individual layers is essential. Moreover, by varying the material and thicknesses of the three layers, the optical properties of the D/M/D or D/A/D films can be tailored to suit different applications.

The main objective of this work was the feasibility study to use Ag-alloy thin film as an IR-reflected layer of heat reflection mirror by simulation technique. The optical constant of Ag-alloy and TiO2 thin films and the performance of Ag-alloy based heat reflection mirrors in this work was evaluated by the transmission spectrum which simulated by the optical thin films design software.

Materials and Methods

Ag-alloy and TiO_2 thin films were deposited on well-cleaned glass slide and Si (100) by a home made DC unbalanced magnetron sputtering system (Fig. 1). The cylindrical chamber of the system has 31 cm in diameter and 37 cm in height was connected to the diffusion pump backed by rotary pump. The system has two unbalance magnetron cathodes, for deposited of Ag-alloy or TiO_2, however, during the deposition of Ag-alloy or TiO_2 films only one cathode was used. The targets are Ag-alloy with 92.5%Ag-7.5%Cu composition and titanium with purity of 99.97%. Prior to deposit each film, the vacuum of the chamber was evacuated to lower than 10-5 mbar.Ag-alloy and TiO_2 films were deposited in DC sputtering mode and DC reactive sputtering mode respectively with 30 nm thickness on glass slides and Si (100) substrate. The thin films deposited conditions are listed in Table 1. The thickness of both films was controlled by deposition rate (thickness per deposited time). The thickness of those films on Si (100) substrate was confirmed by AFM technique (Nanoscope IV, Veeco Instrument Inc.). The transmission spectrum of those films which deposited on glass slide substrate was measured by spectrophotometer (Shimadzu UV-VIS-NIR 3100 spectrophotometer) in the wavelength range of 200 nm to 2500 nm. TFCalc, the optical thin films design software, was employed to evaluate the optical constants such as the refractive index *n* and extinction coefficient *k* of those films from transmittance spectra.

In this work, the feasibility study to use Ag-alloy thin film as an IR-reflected layer of heat mirror was evaluated by the transmission spectrum which simulated by TFCalc based on the heat reflection mirror with TiO_2/Ag-alloy/TiO_2 structure (Fig. 2). In order to simulation the transmission spectrum from TFCalc for evaluated the performance of these heat reflection mirrors, we used the optical constant, n and k, of Ag-alloy and TiO_2 film from the first part and fixed the thickness of TiO_2 layer to 30 nm and then vary the thickness of Ag-alloy layer from 5 nm to 40 nm.



(a) (b)

Fig. 1 DC magnetron sputtering system use in this research
(a) Deposition system (b) Diagram of the sputtering system

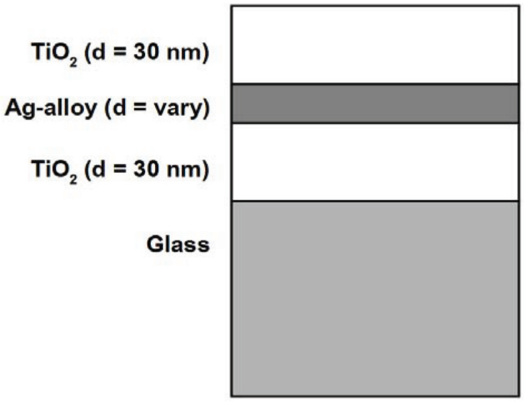


Fig. 2 A three-layer of a thin film system for use as heat reflection mirror

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Table 1 Thin film deposited condition

Parameter	Thin films	
	Ag-alloy	**TiO_2**
Deposition method	DC sputtering	DC reactive sputtering
Sputtering target	Ag-alloy (92.5%Ag-7.5%Cu)	Ti (99.97%)
Substrate	Glass, Si	Glass, Si
Substrate temperature	Room temp.	Room temp.
d_{s-t}	12 cm	12 cm
Base pressure	$5.0x10^{-5}$ mbar	$5.0x10^{-5}$ mbar
Working pressure	$3.5x10^{-3}$ mbar	$5.0x10^{-3}$ mbar
Cathode power	135 W	220 W
Flow rate of Ar	2 sccm	1 sccm
Flow rate of O_2	-	4 sccm
Deposition rate	1.2 nm/sec	0.013 nm/sec

Results and Discussion

Optical constants of thin films

The optical properties of a homogeneous thin film are fully described by its complex index of refraction N=*n*(●)-i*k*(●) where *n* is the real part and *k* is the imaginary part while ● is the wavelength. In this work, we have evaluated the optical constants of Ag-alloy and TiO_2 films by TFCalc. Fig. 3 and Fig. 4 have shown a transmission spectrum of Ag-alloy and TiO_2 thin films respectively which measurement from spectrophotometer and simulation from TFCalc.

The optical constants (*n* and *k*) of Ag-alloy thin films and TiO_2 thin films in the wavelength from 250 nm to 750 nm were evaluated from TFCalc show in table 2. The optical constant of Ag-alloy thin film at 500 nm are n = 0.05 and k = 2.92 which close to the value of pure-Ag [10], while TiO_2 thin film at 500 nm are n = 2.38 and k = 0.

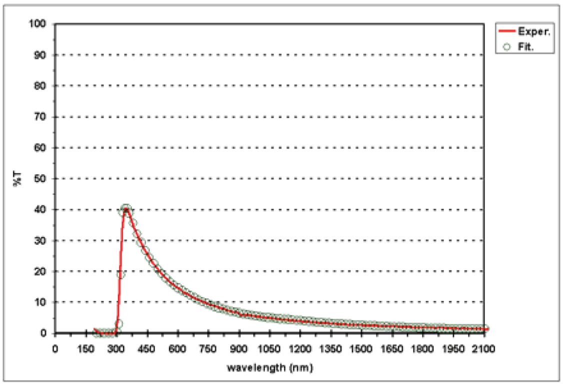

Fig. 3 Transmission spectrum of Ag-alloy thin film with 30 nm thick.
The solid line is the experiment value.
The circles are the simulation values.

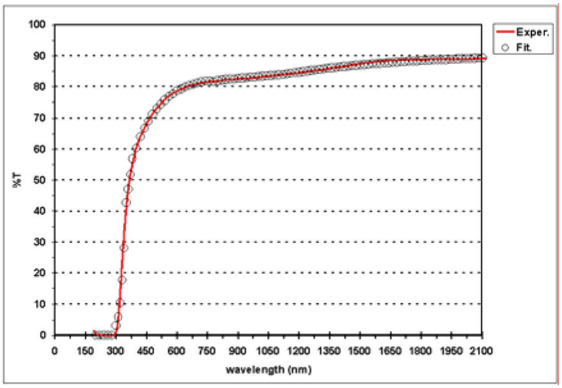

Fig. 4 Transmission spectrum of TiO2 thin film with 30 nm thick.
The solid line is the experiment value.
The circles are the simulation values.

Table 2 Optical constants (n and k) of Ag-alloy and TiO2 films at different wavelengths evaluated from TFCalc

Wavelength (nm)	**Ag-alloy thin films**		**TiO_2 thin films**	
	n	***k***	***n***	***k***
250	0.100	7.00	2.90	8.00
300	0.100	4.40	2.80	2.40
350	0.100	1.65	2.73	0.28
400	0.075	2.10	2.55	0.00
450	0.055	2.53	2.47	0.00
500	0.050	2.92	2.38	0.00
550	0.055	3.30	2.34	0.00
600	0.060	3.65	2.32	0.00
650	0.070	3.99	2.32	0.00
750	0.080	4.72	2.38	0.00

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Feasibility study of Ag-alloy based heat reflection mirror

An ideal heat reflection mirror would be such that it allows visible energy to be transmitted through the window, while the majority of all the IR including that of the sun is reflected away from the window. It means that it has transmittance (*T*) and reflectance (*R*) to be given by *T*=1 and *R*=0 for wavelength = 400 nm to 700 nm (visible region), and *T*=0 and *R*=1for wavelength >700 nm (IR region).

D/M/D or D/A/D films on a glass substrate were use as a spectrally selective filter that reflects IR radiation (due to the properties of the metal or alloy layer) and transmits most of the visible spectrum. The highly reflective metal or alloy thin film, that otherwise transmits very little energy in the visible, was sandwiched between the two dielectric layers that act as antireflective coatings such as to enhance the energy transmitted in the visible region. Thus the visible transmittance was chosen to be the criteria parameter for a given metal or alloy thickness, which in turn controls the IR reflectance.

The heat reflection mirror thin film arrangement wastaken to be: air/D/A/D/glass (Fig. 2). The two dielectric layers are taken as to be of the same material; in this work, we use TiO_2 as dielectric film.The simulations were performed for normal incidence using the TFCalc software. The effects of Ag-alloy layer's thickness on transmittance were simulated at a design wavelength of 550 nm and the substrate was taken to be glass (n = 1.5). The optical constants of Ag-alloy and TiO_2 thin film for use in simulation are taking from table 2

Spectral dependence of reflectance (%*R*) and transmittance (%*T*) of heat reflection mirrors such as TiO_2/Ag-alloy/TiO_2 structure, based on the above design parameters, were simulated for different thickness of Ag-alloy layer. It is clear from Fig. 5 and Fig. 6 that as the Ag-alloy layer thickness increases, the transmittance in the visible region (T_{vis}) decreases while IR reflectance (R_{IR}) increases. An ideal heat reflection mirror is such that it has T_{vis}=1.0 and R_{IR}=1.0. This ideal behavior cannot be achieved in practice because when the Ag-alloy film thickness is changed, one of the two T_{vis} and R_{IR} increase while the other one decreases. Therefore, a compromise is needed. Ag-alloy film thickness in the range of 20-25 nm seems to be a reasonable compromise as for this range of thickness; D/Alloy/D system have values of greater than 65% for both T_{vis} and R_{IR}.(Fig. 7)

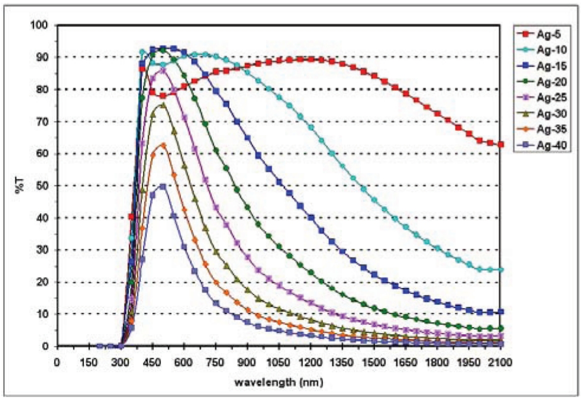

Fig. 5 Transmission spectrum from TFCalc of heat reflection mirror with TiO_2/Ag-alloy/TiO_2 structure for different thickness of Ag-alloy layer.

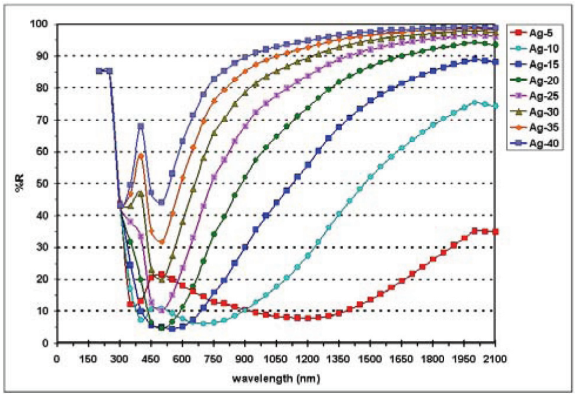

Fig. 6 Reflection spectrum from TFCalc of heat reflection mirror with TiO_2/Ag-alloy/TiO_2 structure for different thickness of Ag-alloy layer.

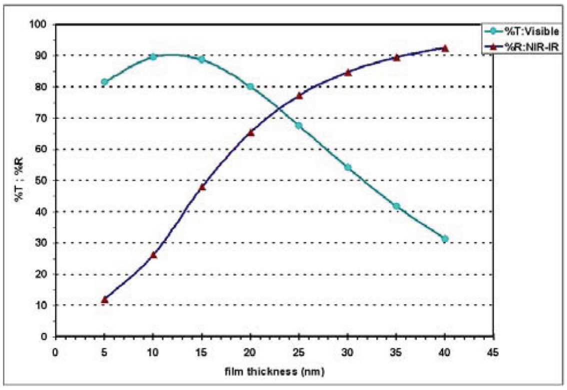

Fig. 7 Transmission in visible region and reflection in IR region of heat reflection mirror with TiO_2/Ag-alloy/TiO_2 structure which vary of Ag-alloy thickness layer

Conclusion

The feasibility study to use Ag-alloy thin film as an IR-reflected layer of heat reflection mirror with D/A/D structure was investigated by simulation technique. The optical constants of Ag-alloy and TiO_2 thin films with a thickness of 30 nm which deposited on glasses slide by DC unbalanced magnetron sputtering were evaluated by TFCalc. The optical constant of Ag-alloy thin film at 500 nm are n= 0.05 and k = 2.92 while TiO_2 thin film at 500 nmare n= 2.38 and k = 0. Spectral dependence of reflectance and transmittance of heat reflection mirrors were simulated for different thickness of Ag-alloy layer. The Ag-alloy layer thickness increases, the transmittance in the visible region (T_{vis}) decreases while IR reflectance (R_{IR}) increases. As the result Ag-alloy thin film could potentially serve as an IR-reflected layer in the system of the heat reflection mirror with D/Alloy/D structure.

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