OPTICAL PROPERTIES OF TITANIUM OXYNITRIDE THIN FILMS AND APPLICATION IN SELECTIVE SOLAR ABSORBER

Zhang Jun

ABSTRACT

The selective solar absorber (SSA) is one of the key units in the concentrated solar power (CSP) system, which is a promising renewable and clean energy generation technique by using solar energy. The titanium oxynitride (TiN_xO_y) based SSA has been paid a lot of attention due to many advantages, such as environmental friendly, low cost, excellent optical property and so on. In this thesis, the optical properties of TiN_xO_y thin films have been investigated and the SSA based on TiN_xO_y thin film has been designed and modeled.

Firstly, the TiN_xO_y thin films have been characterized with various techniques, including X-ray photoelectron spectroscopy (XPS), X-ray diffraction (XRD), atomic force microscope (AFM), transmission electron microscope (TEM), spectroscopic ellipsometry (SE), Hall effect measurement, spectrophotometer, etc. The TEM image confirms the existence of TiN nanoparticles in the TiN_xO_y thin films. The localized surface plasmon resonance (LSPR) of the TiN nanoparticles plays an important part in the optical properties of the TiN_xO_y thin films. Then the SE is carried out to model the dielectric function of the TiN_xO_y thin films by using an optical dispersion model with the consideration of LSPR effect, free electron absorption and interband transitions. It is found that the optical properties of the TiN_xO_y layer can be significantly affected by changing the N_2 flow rate in the sputtering deposition process as a result of the tuning of N/O ratio in the TiN_xO_y thin films.

A single TiN_xO_y thin film based high performance SSA with the structure of SiO_2-TiO_2-TiN_xO_y-Cu has been designed. The SiO_2 and TiO_2 thin films form a double-layer anti-reflection coating (ARC). The TiN_xO_y thin film serves as the absorbing layer and the optical properties can be easily adjusted by the N_2 flow rate, which provides a simple and effective way for the optimization of a high performance SSA. Due to large free electron concentration, the Cu substrate is used as the infrared reflector. The SSA based on the TiN_xO_y layer deposited with the N_2 flow rate of 2 sccm achieves a solar absorbance of 96.29% and a thermal emittance of 6.11% at the temperature of 400 ℃.

In the TiN_xO_y thin film with low N/O ratio (TiNO_L) and TiN_xO_y thin film with high N/O ratio (TiNO_H), three absorption mechanisms have been modeled, including LSPR, free electron absorption and interband transitions. Because TiNO_H has a higher free electron concentration than that of TiNO_L, the absorption due to both the LSPR and free electron absorption in TiNO_H is found larger than that in TiNO_L. The absorption caused by the interband transitions in the TiNO_L and TiNO_H is close to each other. By using TiNO_L and TiNO_H, a double TiN_xO_y layer based SSA with the structure of SiO_2-TiO_2-TiNO_L-TiNO_H-Cu has been proposed. It is found that the double TiN_xO_y based SSA has a wider low reflectance range than that of single TiN_xO_y based SSA.

A low cost SSA with the structure of SiO_2-TiN_xO_y-W/Cu has been fabricated on glass substrate. In the SSA, W/Cu thin film structure is used to serve as an infrared reflector. Without W thin film, the reflectance in both visible and infrared ranges of the SSA increases due to the crystallization of the Cu layer at elevated temperatures. With a W layer with appropriate film thickness, the increase of the reflectance in the visible range can be suppressed to maintain a high solar absorptance, while a high infrared reflectance can be maintained to achieve a low thermal emittance.