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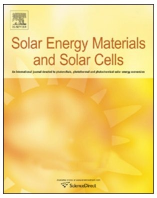

Plasmonic nanostructures for broadband solar absorption based on the intrinsic absorption of metals

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ABSTRACT

In this study, several common plasmonic metals were compared for the development of a broadband absorber. It was found that a broadband absorption region, from 300 nm to 1500 nm, with average values of 89.9%, 91.0%, and 91.6%, was obtained for Ni, Ti, and W absorbers with high imaginary-part permittivities, respectively. The absorption peaks of Ag, Au, and Cu absorbers with low imaginary-part permittivities were mainly in a narrow visible region while the strong magnetic resonance was obtained in the broadband region. A detailed analysis indicated that the intrinsic absorption properties of the metal had a large effect on the broadband absorption ability of the simple-structure absorber and the metal with the high-imaginary-part-permittivity can reach a broadband absorption by the intrinsic absorption without enhanced magnetic resonance. Therefore, the high-imaginary-part-permittivity metal Ni was chosen to fabricate a broadband absorber; the geometric parameters of the Ni absorber were investigated by three-dimensional full-wave simulations to obtain a high-performance absorber. The detailed analysis indicated that the broadband-absorption mechanism can be attributed to the coupling effect of surface plasmon resonance, magnetic resonance, and intrinsic absorption of Ni. A high-performance solar absorber was proposed using Ni disks with two different sizes; the total solar thermal conversion efficiencies reached the values of 0.8909 and 0.8326 at operating temperatures of 800 K and 1000 K, respectively.

1. Introduction

Plasmonic metamaterial absorbers have attracted a significant attention owing to their high electromagnetic performances in various applications including imaging [1], sensing [2], and energy harvesting [3,4]. Over the past decades, solar selective absorbers including plasmonic broadband metal absorbers, have attracted a large interest with the progress of the green-energy technology, in particular, aiming to increase the utilization efficiency of solar energy. For example, in the field of thermophotovoltaics (TPVs), first, solar radiation is absorbed by a solar selective absorber, and then a thermal emitter is heated by the solar selective absorber to a high temperature. Therefore, the emitter can emit most of the radiation in the infrared region, corresponding with the energy bands of the semiconductors in the photovoltaic cells. In this TPV system, solar energy is transferred to thermal energy; the thermal radiation is in the infrared region, converting a wide spectrum region of solar energy into a narrow infrared range of thermal radiation suitable for photovoltaic cells. The introduction of an ideal solar absorber in the solar TPV system could enhance the system efficiency to 85% [5].

A metal–dielectric–metal absorber consists of a metallic nanostructure array and metallic film, separated by a thin dielectric film. It can achieve an almost-perfect absorption by concentrating the electromagnetic field in the dielectric gap based on the surface-plasmon-resonance-(SPR) or cavity modes, which has attracted a significant interest. This type of metal–dielectric–metal absorber has been extensively investigated both theoretically and experimentally over the past few years [6–9]. For example, Lei et al. [10] simulated the optical properties of Au metal-insulator-metal grating nanostructures and four main absorption bands with efficiencies nearly 100% were obtained by modulating duty cycle of the metal grating. Hao et al. [11] designed a metallic absorber with an absorption peak of 88% at a wavelength of ~ 1.58 μm based on the plasmonic metal Au. In addition, a concept of a magnetic-polariton-enhanced absorber based on the tungsten metal–dielectric–metal structure was presented by Wang et al. [12]. Simulation results showed an averaged absorption efficiency of 0.8 in the

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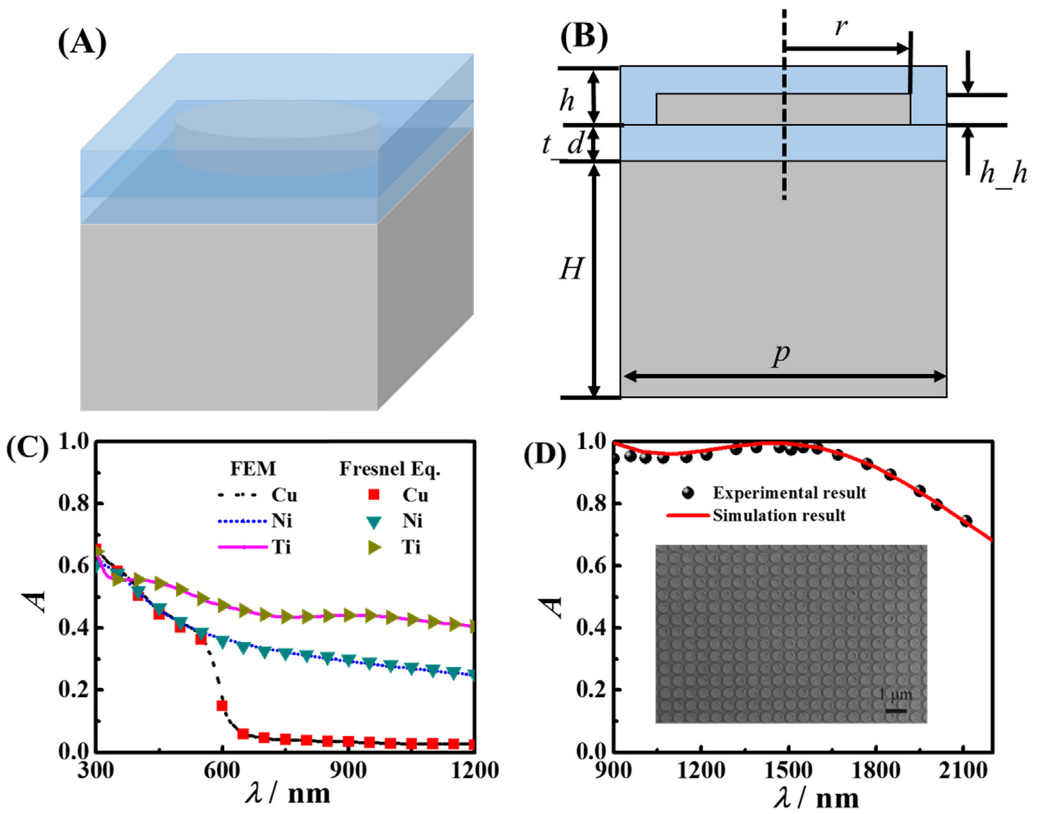

Fig. 1. (A) Schematic of the solar selective absorber. (B) Cross section of the solar selective absorber with the parameters used for the calculation. (C) Comparison between the FEM calculated results and theoretical results from the Fresnel equation for films (the thickness is 100 nm). (D) Comparison between the FEM simulation result and experimental results for the Ti absorber and the inset is a scanning electron microscope (SEM) image of sample [25].

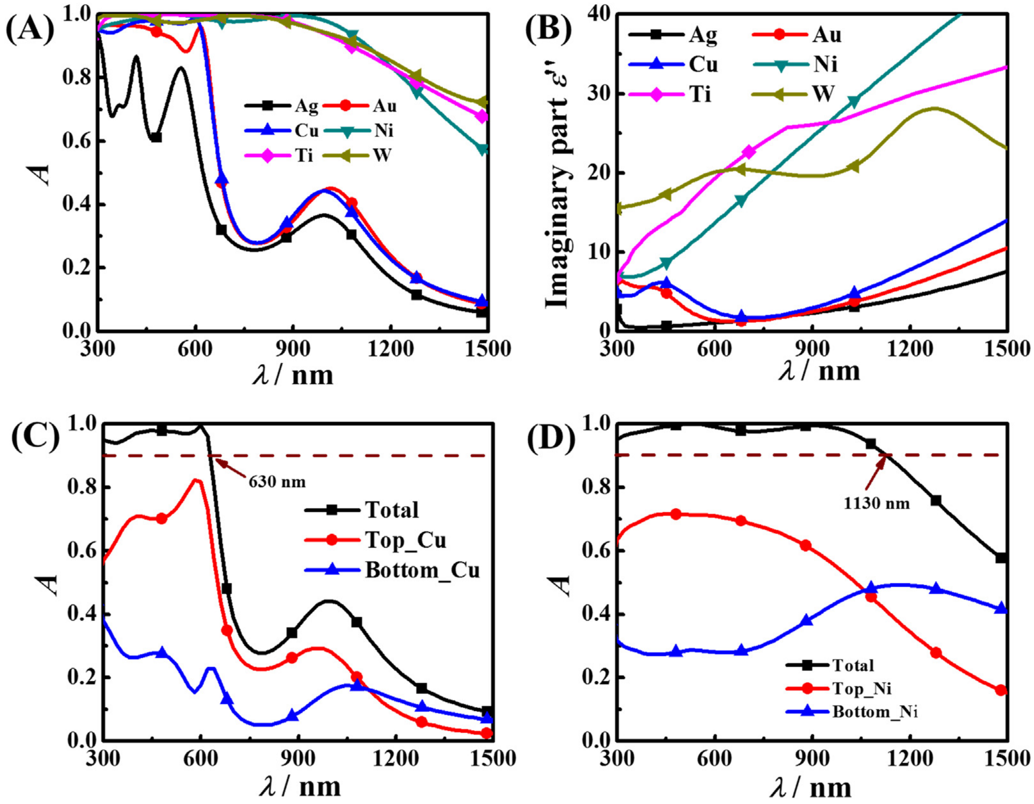

Fig. 2. (A) Spectral absorptances in the region of 300–1500 nm for various absorbers. (B) Imaginary parts of the permittivities for various metals. (C) and (D) Total absorptances in the top disk and bottom layer of the Cu and Ni absorbers, respectively.