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Optical constant measurements of solar thermochemical reaction catalysts and optical window

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ABSTRACT

Because of the ultra-high operation temperature in solar thermochemical reactors, radiative transfer accounts for the majority of the total heat transfer. Determining the radiative characteristics of catalysts during solar thermochemical reactions is critical for numerical calculations. Optical constant of material is only determined by the intrinsic properties of materials and not related to the micro-structural morphology. In this study, optical constants of four typical types of metal oxides often used as catalysts during solar thermochemical reactions were obtained by using infrared variable angle spectroscopic ellipsometry. In addition, the variation of optical constant of quartz window with temperature was also investigated using infrared variable angle spectroscopic ellipsometry in the far infrared spectral region. The experimental results indicated that the peak values of the refractive index and extinction coefficient of the optical window decreased with increasing temperature, and the degree of polarization of optical window decreased with increasing temperature and already decreased to 40% at 673 K in the spectral range of 7.2–7.5 μm. In addition, the refractive index and extinction coefficient varied sharply with increasing wavelength for both the catalysts and optical window.

1. Introduction

The supply of secure, clean and sustainable energy is arguably the most important scientific and technical challenge facing humanity in the 21st century [1]. Earth's ultimate recoverable oil resources, estimated at three trillion barrels, contain 1.7×10^{19} kJ of energy, which the sun supplies to the Earth in 1.5 days [2,3]. In China, the annual hours of better solar irradiation are provided, and the annual irradiation amount is approximately 5800–6600 MJ/m^2 [4,5]. The available zone is approximately 2200–3000, and the annual irradiation amount is approximately 5000–5800 MJ/m^2. As a pollution-free and renewable resource, solar energy has received increasing attention and is an effective way to relieve the issues of global warming and fossil fuel crisis [6]. Among the types of solar thermal utilizations, solar thermochemical reaction represents one comparatively momentous part [7–9].

A schematic of the solar thermochemical reaction is illustrated in Fig. 1 [10]. The solar energy is concentrated at a focal point by concentrators, thus providing medium-to-high temperature heat. For solar thermochemical reactions, all step endothermic reactions can take advantage of concentrated solar radiation as energy source of high-temperature process

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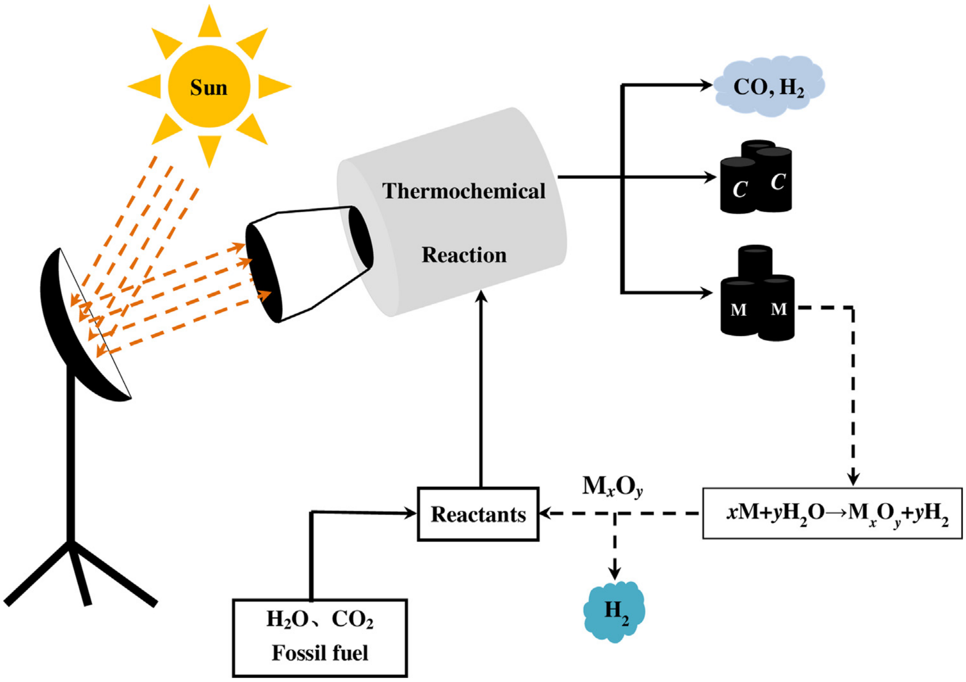

Fig. 1. Overall schematic of solar thermochemical reaction (adapted from Ref. [10]).

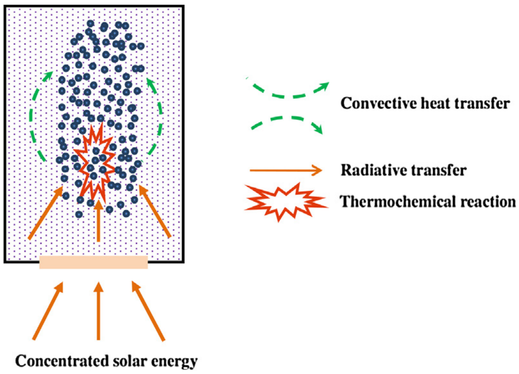

Fig. 2. Roles of catalysts during the solar thermochemical reactions (adapted from Ref. [16]).

heat [11]. When concentrated solar energy is employed as an energy source in the production of raw materials for the synthesis of fuels, synthetic liquid fuels are produced from the reactions between H_2 and CO originating from solar-aided dissociation processes as well as metal oxide powders [12,13].

The benefits of solar thermochemical reactions are: (1) the calorific value of the feedstock is improved, (2) gaseous products are not contaminated by the byproducts of combustion, (3) the discharge of pollutants to the environment is reduced, and (4) the need for energy-intensive processing of pure oxygen is eliminated [14,15].

As illustrated in Fig. 2, the catalysts act as the roles of concentrated solar energy absorption, heat transfer and catalysts during the solar thermochemical reaction [16]. Many researchers and institutions [17–29] have attempted to find new types of solar thermochemical catalysts. Nakamura [25] was the pioneer of using Fe_3O_4/FeO for two-step thermochemical decomposition process to produce hydrogen and oxygen from water utilizing concentrated solar radiation. Miller et al. [26] had developed a novel concentrating solar power (CSP) driven metal-oxide-based endothermic chemical reactions, a mixture of $Co_{0.67}Fe_{2.33}O_4$ and YSZ in a 1:3 wt ratio were used as catalyst. The production of hydrogen from water using solar energy via a two-step thermochemical cycle by ZnO/Zn was conducted by Steinfeld [27], endothermic step was the dissociation of ZnO (s) into Zn (g) and O_2 at 2300 K using concentrated solar energy as the source of process heat and the exothermic step was the hydrolysis of Zn(l) at 700 K to form H_2 and ZnO (s), while hydrogen and oxygen were derived in different steps without the need of high-temperature gas separation. The thermochemical cycle for H_2 production based on CeO_2/Ce_2O_3 oxides was first put forward by Abanades and Flamant [28]. Materials of the perovskite structure and of