

Solar energy absorption mediated by surface plasma polaritons in spectrally selective dielectric-metal-dielectric coatings: A critical review



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ABSTRACT

The effective use of solar energy has become significantly important due to unnatural weather changes and fossil fuel exhaustion. Concentrating Solar Power (CSP) technology is a promising approach to harvest solar energy in the form of heat using solar selective absorber coating. These coatings are expected to absorb maximum incoming solar radiation ($\alpha \geq 0.95$) and prevent loss of the absorbed energy as infrared radiation ($\epsilon \leq 0.05$). Efficiency of the absorber coating can be evaluated by a metric called “Solar selectivity (α/ϵ)”. In recent years, a number of attempts have been made to achieve remarkable selective property and high temperature stability of the absorber coating using the concept of Surface Plasma Polaritons (SPPs). The SPPs have the capability to capture solar energy by confining electromagnetic field at the metal-dielectric interface. Solar absorption, can be maximized by tailoring the optical constants of the metal and dielectric. In this review, we have described different types of solar absorber coatings with particular emphasis on dielectric-metal-dielectric (DMD) -based absorber coatings. We have presented a brief theoretical overview to comprehend physics of DMD coatings. This review additionally highlights some of the case studies based on the DMD -based absorber coatings with the high temperature stability and their importance in the context of CSP technologies.

1. Introduction

It is widely accepted that the use of fossil fuels like petroleum, natural gas and coal gives rise to serious environmental concerns with their essential energy usage abilities [1]. All stages of fossil fuel usage have severe impact upon the environment, from recovery to storage and end use. There are alternative sources of energy being developed to replace the use of fossil fuels. Solar energy, a source of a clean environmental friendly energy and the largest available carbon-neutral energy source, can be considered as a potential solution to the environmental pollution as well as the world energy crisis. Every day, almost 400 trillion kWh energy from the sun touches surface of the earth in the form of electromagnetic radiation [2]. It does not disrupt the environment or create a threat to the eco system the way fossil fuels do.

The solar energy can be harnessed by two approaches, as passive solar technique and active solar technique. Main features of a well-designed passive solar systems are structures, design and position,

which can be optimized to use solar energy [3,4]. Active systems use mechanical and electrical equipments to utilise the solar radiation into a more usable form, such as heat or electricity [5,6]. The most well-known active solar techniques are photovoltaic panels and solar-thermal electric energy systems [7]. Though solar photovoltaics have attracted significant attention within the energy community, solar thermal energy systems recently have become prominent in the field of power generation, as such technology has proven its performance in production of clean, secure and low cost energy. These Solar thermal systems are also characterized by its simplicity in the manufacturing process, scale up potential, low technical and financial risk [8]. Unlike photovoltaic technologies, solar thermal plants have the scope to store the heat energy for some period to facilitate a successful continuous and year round supply of electricity. Solar thermal plants are usually equipped with the thermal energy storage (TES) and backup systems (BS) to provide electricity in the night hours or during cloudy days when the sun is not available [9]. Among the solar thermal technologies, concentrating Solar Power (CSP) is one of the most mature

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technology which has shown a great promise for the future and is currently being deployed worldwide. According to available technology road map of International Energy Agency (IEA), the CSP systems, by 2050, could provide 11.3% of global electricity with 9.6% from solar power and 1.7% from backup fuels (i.e., fossil fuels and biomass) [10].

The first commercial CSP plant was constructed by Luz International Ltd. with a capacity of 354 MW in Mojave Desert, California in the period of 1984–1991 [11]. However, efforts to duplicate similar plants suffer a setback as the reduction in fossil fuel cost dismantled the policy framework of CSP systems. A new era of CSP began in 2006 when the first central receiver tower plant, PS10, was commissioned with an overall capacity of 11 MW in Sevilla, Spain [12]. This achievement led to the approval of California Energy Commission in September 2010, for the construction of four more solar thermal power plants in California, USA, with an overall capacity around 1000 MW. The solar energy experts have estimated that CSP systems with about 118 GW could be installed by 2030 and 1504 GW by 2050 in the USA [13]. Numerous commercial projects for solar thermal plants have been taken up in Europe as well. The European Solar Thermal Electricity Association (ESTELA) estimates that the total installed capacity could reach up to 1000 GW by 2050 [14]. The government of India has also taken an initiative by launching an ambitious project, called Jawaharlal Nehru National Solar Mission (JNNSM) with a funding of USD 930 million in 2009 [15]. This project, complemented by solar policy framework, has set a goal to account for 20,000 MW solar power by 2022. The project will promote favourable conditions for solar manufacturing capability, particularly the solar thermal applications. Other countries such as China [16], Israel [17], South and north Africa [18,19], Australia [20], Algeria [21], and Italy [22] are also doing remarkable progress on current commercial development of the solar thermal plants.

The CSP technologies [23,24] can be categorised into four types depending on the way they focus the solar radiation and the technologies used to receive energy:

- the parabolic trough collector
- the solar tower
- the parabolic dish concentrator
- the linear- Fresnel reflector.

The schematic of the four types of CSP system is presented in Fig. 1. Each of these different CSP technologies have some major features along with their own advantages and drawbacks, which have been illustrated in detail elsewhere [25,26].

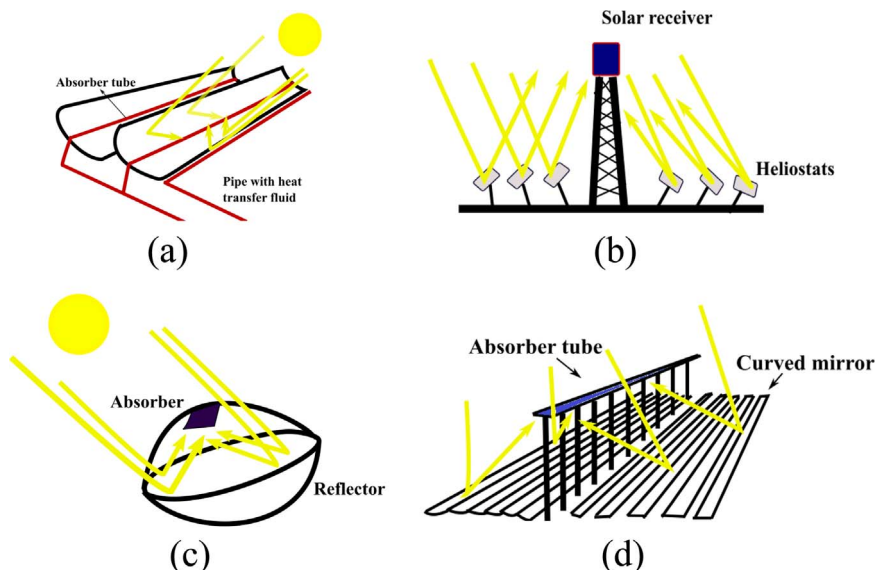


Fig. 1. Schematic of four CSP systems a) parabolic trough collector b) solar tower c) parabolic dish concentrator and d) linear Fresnel reflector [23,24].

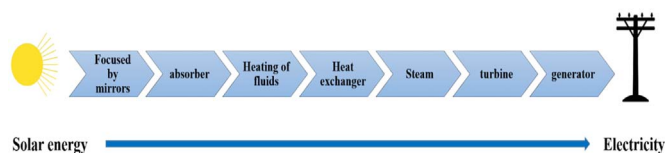


Fig. 2. Schematic of the mechanism to produce electricity from solar energy in CSP systems.

CSP plants produce electricity in the same way as other conventional power plants, but using solar radiation as energy input. In CSP systems, the solar irradiation is concentrated several times by mirrors, which have very high reflectivity to reach high energy densities. Recently, a new class of reflector materials based on Cu–Sn intermetallics with tailored substitution of aluminium or zinc with a bulk reflectance of 89% has been developed [27]. In addition, a novel δ -phase based Cu–Sn mirror through electrodeposition has been reported, the material exhibits $\sim 80\%$ of specular reflectance [28]. These mirrors would enable attaining higher temperatures in the focus of the concentrating system.

Materials that help in converting light energy harnessed from the Sun into heat are referred as absorber materials. Usually, the absorber materials are deposited onto the receiver tube, where heat transfer fluids are heated by the absorbed heat and the temperature of the fluid reaches around 400°C . The heated fluid is driven through a series of heat exchangers to produce superheated steam. The steam is then used to operate a conventional power cycle, such as a steam or gas turbine or a stirling engine, which drives a generator (see Fig. 2).

Hence, a typical CSP system has four essential components such as concentrator, receiver or absorber, transport/storage media system (molten salt, gas, air etc.) and power conversion device. Of all components, receiver plays a vital role in determining the efficiency of the CSP systems. The nature of the absorber coating, deposited on to the receiver tube, often controls conversion of solar energy to heat. An ideal absorber should absorb as much of the incident sunlight as possible ($\alpha \geq 0.95$). This implies that the reflectance should be minimised in the entire solar spectrum. Simultaneously, the loss of the heat to the surroundings via convection or conduction, i.e. emittance ($\epsilon \leq 0.05$), should be very low, with a thermal stability up to the operating temperature of the receiver, usually of the order of 400°C . Thus, there are conflicting requirements of strong absorption in the solar spectrum, with minimum emission in the far infrared range (Fig. 3).

The design of the absorber surfaces initially attracted attention

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