Experimental study on optical property and stability of Ag-glycol nanofluid for spectral splitting photovoltaic/thermal

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ABSTRACT

In this paper, Ag nanoparticles (NPs) were synthesized through reduction method and suspended in glycol. The obtained Ag nanofluid (NF) exhibited high absorptivity in the visible light wavelengths and good transmittance in the spectral response range of silicon PV cell. In addition, the effect of high temperature on spectral characteristics and stability of Ag NFs were measured by gravitational sedimentation experiments and transmission spectroscopy. The results showed that a slight increase in transmittance was observed in visible region when Ag NF was heated to 100 °C. In contrast, the spectral characteristics in the near-infrared band (NIR) presented different tendencies along with the rise of temperature. The experimental results also demonstrated that as-obtained Ag NFs performs stable at high temperatures, thus can be an optimal spectral filter for the spectral splitting PV/T system.

Keywords: Ag-glycol NF, optical property, high temperature stability

INTRODUCTION

As a promising hybrid solar energy converter, NF-based spectral splitting photovoltaic/thermal (NSS-PV/T) system has attracted increasing attention in recent years. NSS-PVT has several advantages over conventional PV/T converters: 1) NF operates as both solar volumetric absorber and heat transfer fluid; 2) The NF filter realizes the "thermal decoupling" so that photovoltaic and photothermal systems can simultaneously operate at their suitable operating temperatures; 3) NF filter is different from solid filters, it has the potential of dynamically changing its optical performance; 4) From the economic point of view, the NF is more capable of achieving large scale spectral beam splitting solar energy system in the existing technical solutions.

Most of the researches on NSS-PV/T are concerning on the energy conversion process. In order to figure out the system performance and optimal configurations, a lot of investigations has been carried out based on theoretical analysis and numerical simulations. According to the study of Abd El-Samie et al.[1], with Therminol VP1-SiO_2 NFs, the thermal and electrical efficiencies of the NSS-PVT can achieve 59% and 11%, respectively, which is much higher than conventional PV systems. Some of the researches also tried to develop new multi-physics models and methods for further investigation of the NSS-PV/T system, such as the study of Crisostomo et al.[2] and Ju et al.[3]

Despite researches mentioned above, the experimental work also proceeded continually. An et al. [4] designed an innovative system to test the performance of the hybrid PV/T system with polypyrrole NF filter. The temperature of photothermal unit limited by the boiling temperature of aqueous polypyrrole NF, was lower than 100℃. They followed up their initial study with another study using the same experimental setup but with Cu9S5 NP suspended in oleylamine fluid with back-contact monocrystalline solar cells [5]. Notably, this work is the first work to demonstrate the concept experimentally at temperatures exceeding 100 °C with a peak temperature recorded of 124.9 °C. Otanicar et al. [6] experimentally investigated that CPV/T collector can provide thermal energy above 100°C when Au-ITO/ Duratherm S as the filter. For these experimental researches, several NFs exceeding 100 °C has already been used as filters. However, the stability together with the optical properties of NFs operating at high-temperature is still a big challenge for NSS-PVT system development.

The main work of this paper is to study the stability and optical properties of Ag NFs at high-temperatures. Based on this, Ag NPs were synthesized through reduction method, and the glycol-based Ag NF was prepared by a two-step method. In addition, a specially-designed test bench was used to measure the spectral characteristics of Ag NFs at certain temperatures. The effect of temperature on spectral characteristics and stability of the NF filter were analyzed in detail. The paper contributes to the researches on the stability and spectral characteristics of NFs at high temperatures.

2 PREPARATION OF AG NFS

As a typical SPR metal, Ag NPs demonstrated the superior capability for photon capture in the visible region. Applying Ag NPs in absorption filter were verified with the feasibility for NSS-PVT applications. In present work, spherical Ag NPs were prepared using a procedure described in Ref. [7].

2.1 Synthesis and characterization of Ag NFs

In the procedure of synthesis, 5 mL of anhydrous glycol was preheated to 160 °C in high-temperature reactor and kept heating for 1 h to oxidize glycol to ethanolaldehyde using oxygen in the air. Afterwards, a 3-mL of a glycol solution of $AgNO_3$ (concentration: 0.085mol/L) and a 3-mL of PVP (0.13mol/L) were simultaneously added to the hot glycol using a two-channel syringe pump at a rate of 0.375 mL/min. The reaction mixture was then continued with heating at 160 °C for 40 min. Magnetic stirring (at a rate of ~400 rpm) was maintained throughout the synthesis. Nano-Ag element was prepared by deoxygenation with ethanolaldehyde. As shown in Fig. 1, the freshly prepared nano-Ag solution was yellow-green. The anhydrous alcohol was chosen as cleaning agent in the separation of Ag NPs. Ethanol can dissolve glycol and other organic substances attached to the surface of particles, and easily vaporized. In our experiments, a certain amount of as-prepared nano-Ag solution was dissolved in ethanol and then washed by high speed centrifuge. Pure Ag NPs can be obtained after repeated centrifugal purification. The as-obtained Ag NPs were redispersed in ethylene glycol. Then, the suspension was ultrasonically vibrated for 30 min in an ultrasonic cleaning tank to form a long-term stable NF without any dispersant as shown in Fig. 1.

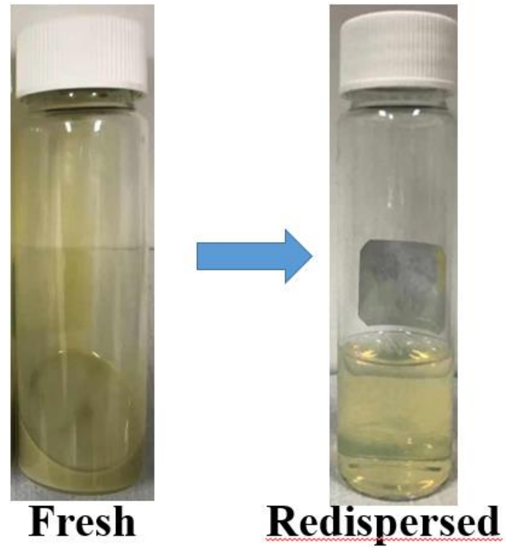

Fig.1 The fresh nano-Ag solution

The morphology and size of the Ag NPs can be observed through the transmission electron microscopy (TEM) images in Fig. 2. The sample, which was dispersed into the anhydrous alcohol in advance, showed nanorods and nanospheres, which has an average diameter of 200 nm with narrow size distribution.

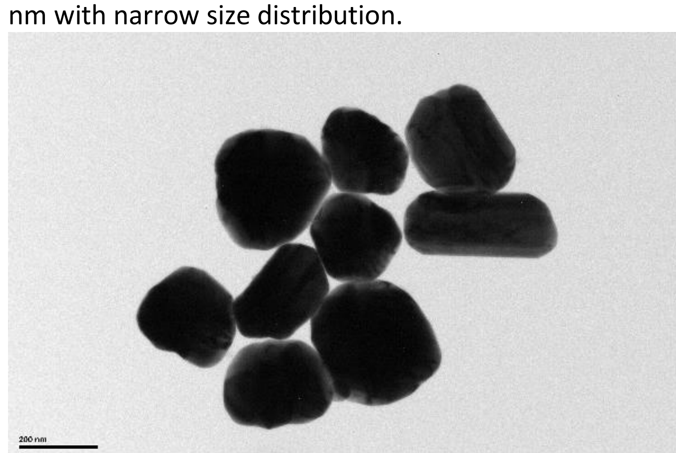

Fig.2 TEM images of Ag Nps at 160 °C

The stability of the obtained Ag NFs were measured by gravitational sedimentation experiments. After 144 h of standing, no obvious precipitation occurred, which indicated that the obtained Ag NF had a good stability.

2.2 Optical property of Ag NFs

The optical property of the NFs plays significant roles in liquid absorption filters. For an NSS-PV/T system with silicon cells, the ideal NFs should exhibit high transmittance in the specific band of 730–1130 nm [8], and simultaneously have high absorption at the remaining spectral range of sunlight. Based on this, the combination of Ag NP and glycol could be an ideal alternative. In this paper, the transmittance of Ag NFs was measured in wavelengths ranging from 250 to 2500 nm with 2 mm of the optical path by combining the two spectrometers (Ocean Optics NIRQuest and Ocean Optics QEPro) with different measuring ranges, as shown in Fig. 3. Glycol has high transmittance at whole wavelengths from 250-2500 nm. In contrast, when Ag NPs are suspended, strong absorption in the visible waveband is observed. Notably, the wavelength of 430 nm exhibits an LSPR peak, which could be used as an excellent means to adjust absorption in visible light band. Therefore, the as-prepared Ag NFs can be an ideal spectral filter for NSS-PV/T system with silicon cells.

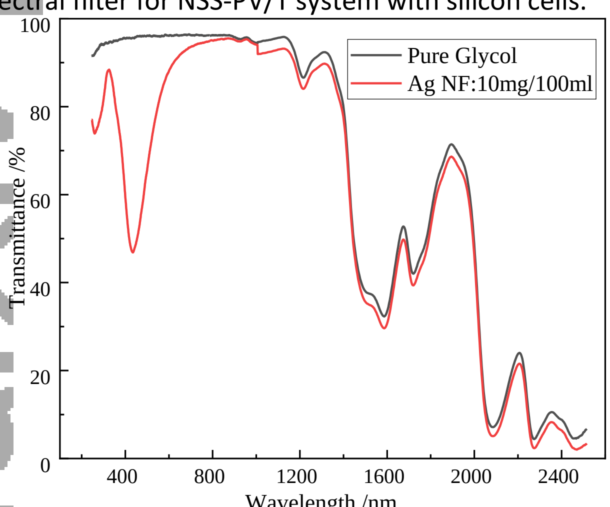

Fig.3 Spectra of the glycol and the NFs with different concentrations

3 STABILITY AND OPTICAL PROPERTY OF HIGH-TEMPERATURE AG NFS

The spectral NFs applying in NSS-PVT usually works at elevated temperature conditions. However, high temperature has a significant effect on the optical properties and stability of NFs. Therefore, it is necessary to investigate the effect of the temperature dependency of stability and optical property of NFs.

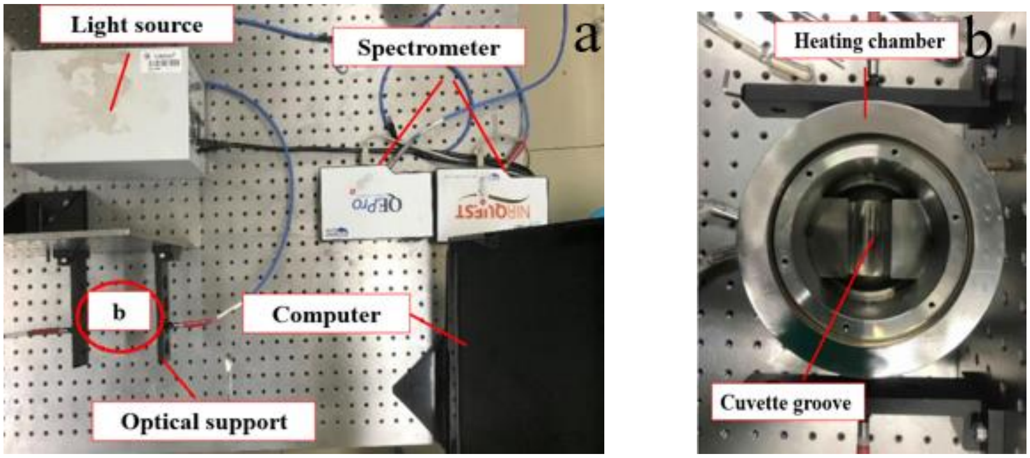

Fig. 4 The test bench for spectral measurement of high-temperature NFs (a) and the heating chamber (b).

3.1 Test bench for spectral measurement of high-temperature NFs

Here, we built a test bench for spectral measurement of high-temperature NFs to record real-time spectral characteristics of high-temperature NFs. The test bench is shown in Fig. 4a. By combining the two spectrometers with different measuring ranges, the transmission spectrums of NFs at different temperatures can be measured directly. To ensure the steady temperature of NFs in the process of spectral measurement at high temperatures, a specially designed high-temperature heating chamber with the temperature range of room temperature (RT, 20℃) to 300 °C was manufactured, which is shown in Fig. 4b. The cuvette groove in the middle of the chamber was used to lock the samples during the tests. It was proved that the internal temperature fluctuation of the heating chamber was lower than 1 °C under steady-state conditions.

3.2 Stability and optical property of high-temperature Ag NFs

Considering the features of prepared NFs, the spectral characteristics of high-temperature Ag NF were measured ranging from RT to 100℃, as shown in Fig.5. Ethylene glycol was oxidized by oxygen in the air at high temperature. Therefore, the heating temperature did not exceed 100 °C in present work. Ag NF, as discussed earlier, exhibited strong absorption in the visible waveband at RT. With increasing temperature, the LSPR peak of the Ag NP had no apparent peak shift. However, the absorption peak exhibited a decrease in intensity with temperature increases, as shown in the inset of Fig. 5. Meanwhile, the transmittance in the range of 1300-2500 nm presented complex tendencies along with the rise of temperature. In the ranges of 1480-1930nm and 2065-2500nm, the transmittance of Ag NF gradually increased from RT to 100 °C, and in the ranges of 1300-1480nm and 1930-2065nm, the transmittance performs opposite tendencies with temperatures.

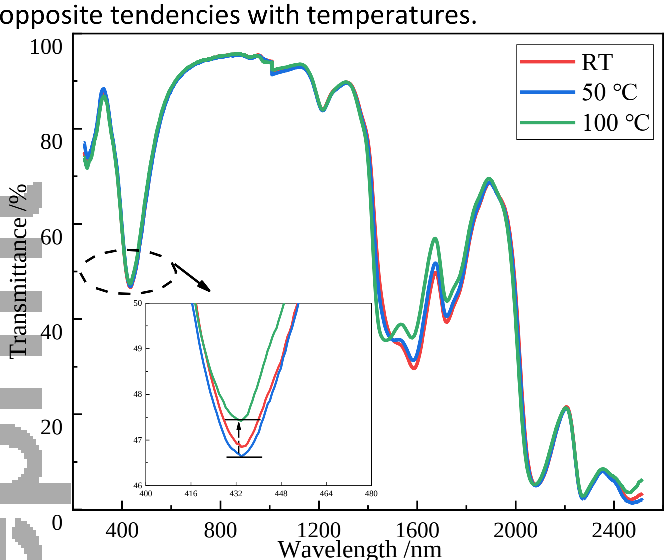

Fig. 5 Spectra of Ag NF at different temperatures

In addition to excellent optical properties, high-temperature stability is also an important criterion to determine whether the base solution is suitable for NSS-PVT system. Here, the heated samples were maintained at high temperature for a certain time and then cooled to RT, which was shown in Fig.6. Within the test temperature range, no obvious loss in transmittance was observed comparing the secondary cooling sample with the unheated. Thus, as-obtained Ag NFs with superior optical properties and high-temperature stability can be an ideal spectral filter for the NSS-PVT system

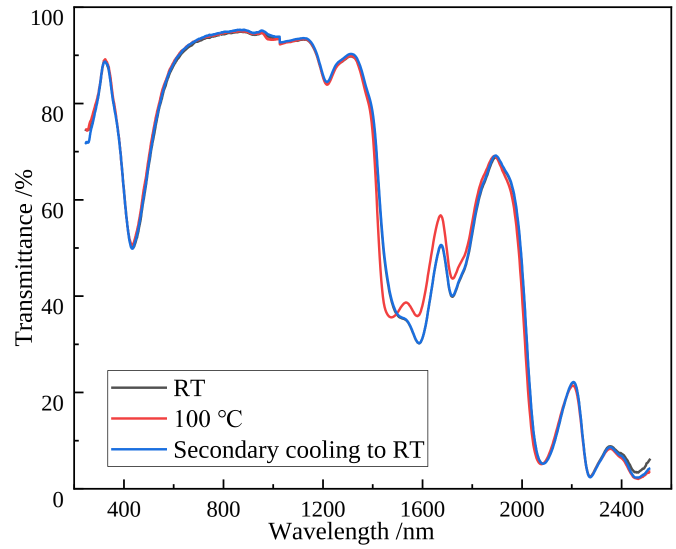

Fig. 6 Stability test of high-temperature NF

4 CONCLUSION

In this study, Ag NPs with tunable absorption capability were prepared and suspended in glycol as an ideal spectral filter for NSS-PVT system. The high-temperature spectral characteristics of as-obtain Ag NFs were measured by self-built test bench for spectral measurement. The effect of high temperature on spectral characteristics and stability of Ag NFs were analyzed in detail. Salient findings are summarized as follows:

1) Ag NPs were prepared by reduction method. And the obtained Ag NF based glycol has a tunable absorption capability in the visible regions, and the wavelength of 430nm exhibits an LSPR peak;
2) For Ag NFs, a slight increase in transmittance was observed in visible region when heated to 100 °C compared to the RT. In contrast, the spectral characteristics of high-temperature Ag NFs in NIR had the same trend as those of pure glycol. Moreover, the experimental results demonstrated that as-obtained Ag NFs with high-temperature stability, which can be an ideal spectral filter for the NSS-PVT system;

For further studies, the following works will be carried out: 1) The effect of reaction temperature on the morphology and distribution of Ag NPs will be further analyzed; 2) Considering that ethylene glycol can be oxidized at high temperature, the heating chamber will be improved by efficient oxygen removal to obtain the spectra Ag NFs at higher temperature; 3) Based on the as-obtained spectra at high temperature, we will use the existing inversion calculation method to get the optical constants of Ag NF, which is of great significance to improve the simulation or theoretical analysis of the NSS-PVT system at high temperature .

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