Research Article

Plasmonic Hybrid Thin Film for Broadband Absorption and Characterization of Its Optical and Electrical Properties

Sookyong Moon

Structures and Advanced Composite Research Unit, Japan Aerospace Exploration Agency (JAXA), 6-13-1 Osawa, Mitaka, Tokyo 181-0015, Japan

Correspondence should be addressed to Sookyong Moon; moon.sookyong@kist.re.kr

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We developed a simple and effective technique for fabricating a hybrid nanostructure of graphene-silver nanoparticles. The structure was prepared by stacking method with polyvinylpyrrolidone as a stabilizer. The chemical linking of G-PVP-Ag is possible through PVP-based ligand chemistry. The resulting hybrid film exhibited 87% transparency. The electrical properties under UV light increased compared with only one material. The conversion efficiency of a solar cell fabricated with the hybrid structure also increased approximately by 1.5% compared with that of solar cell fabricated without the hybrid film.

1. Introduction

Solar cells are under development to convert light into electricity at low cost and with high efficiency. Many researchers have reported methods for reducing the processing costs of high-efficiency cells [1–3]. Improving the efficiency of solar cells requires the development of materials with high optical transparency, a high absorption rate of sunlight, and high electron and hole mobility with a light weight. Thus, many groups researched about thin film type solar cell. But a large fraction of the incident light in the solar spectrum is not absorbed on this type. That shows nonabsorbable wavelength regions. To overcome this problem, some researchers have proposed multilayer-thin-film solar cells. However, in such cells, the photocarriers are generated near the p–n junction. Charge carriers generated far from the p–n junction are not effectively collected because of bulk recombination. The weight of multilayer structure is also problematic. Therefore, the development of solar cells with a new structure is necessary.

Recently, some researchers have proposed incorporating metal nanoparticles (NPs) into solar cells, resulting in the so-called plasmonic solar cells. Plasmons are created when incident light excites coherent oscillation of the free electrons in

metal NPs. This phenomenon gives rise to unique properties such as an intense absorption feature and enhanced electromagnetic field; these properties have been exploited in various applications ranging from sensing to enhancing fluorescence. And the introduced metal NPs increase the lifetime of light via the trapping effect [4–7]. Silver NPs (Ag NPs) are used to efficiently harvest light and enhance optical spectroscopy. Ag NPs strongly interact with light because the conduction electrons on the metal surface undergo a collective oscillation when excited by light at specific wavelengths.

On the other hand, the plasmonic effect closely related to the particle shape and size. Compared with spherical particles, cylindrical and hemispherical particles are much more effective at scattering light into substrate and keeping the light trapped within the substrate via enhanced near-field coupling. For the entire solar wavelength range, the fraction of light scattered into the substrate is much higher for cylindrical and hemispherical particles than for spherical particles [4, 8].

Graphene (G) exhibits high transparency, high conductivity, high durability, and good flexibility. This unique combination of properties makes this material attractive for a wide range of potential applications. In this study, we investigated hybrid materials containing G and Ag NPs for increased

FIGURE 1: Schematic of the graphene (G) and silver nanoparticle (Ag NP) hybrid structure; (a) various Ag nanoparticle solutions, (b) graphene solutions, and (c) stacked structure of hybrid film.

solar cell efficiency via broadband absorption. The resulting hybrid structure exhibited good electron mobility and high transparency, rendering it suitable for use in various devices.

The as-prepared graphene surface was hydrophobic and inert; thus, surface modification was required. Polyvinylpyrrolidone (PVP) is soluble in both water and other polar solvents. We synthesized G–Ag NP hybrid materials using PVP as a stabilizer. In previous studies, hybrid structures were prepared using a solution method [9, 10]. However, controlling the amount of Ag NPs deposited onto G surfaces is difficult with this process, which tends to result in films with low transparency. Thus, a new method for fabricating such hybrid materials is needed. In this study, we propose a very simple and facile method for preparing hybrid structures by stacking layers using PVP.

2. Experimental Methods

Ag NPs and G solution was prepared by modified previous research [11, 12]. For synthesis of Ag NPs, 0.6 mM FeCl_3 solution, 2.3 mM AgNO_3 , and 1 mM–263 mM PVP (K10, K40) are added in ethylene glycol (EG). The mixture was heated at 150 for 90 min and the solution cooled down to room temperature. The acetone and DI water were added in the synthesized solution and centrifuged at 2000 rpm for 20 min. This process was repeated several times and redispersed in ethanol.

For G solution, the synthesized GO dispersed ethanol with 1 g PVP (K10). The solution sonicated for 2 h. The solution was drop coated on to substrates (FTO glass and polyethyleneterephthalate (PET)) according to step by step, and the resulting materials were heated at 60 for 3 min. The film on FTO glass was tested for solar cell properties and the PET tested for the other optical properties, respectively.

3. Results and Discussion

Figure 1 shows the concept of structure of the Ag NP–G hybrid film. The Ag NPs were well distributed on the G layers.

FIGURE 2: Transmittance of the hybrid material and SEM images of silver nanowire (Ag), graphene (G), and the prepared hybrid material (Ag-G).

We synthesized various Ag NPs containing silver nanowires (Ag NWs). Different Ag NP shape and size exhibited different optical properties (Figure S1 in Supplementary Material available online at <https://doi.org/10.1155/2017/8319463>). The two types of Ag NPs exist as mixtures of Ag NPs and Ag NWs. The wires and particles were attached to the G layer. Some particles detached from the G surface because of handling during the preparation and observation of the sample. The Ag NWs and NPs were also partially covered with PVP. Therefore, the chemical linking of PVP–G with Ag is possible, likely through PVP-based ligand chemistry [13, 14].

We investigated the transparency of the synthesized hybrid material (Figure 2). The transmittance of the coated Ag nanomaterial was 95% and the hybrid material was 85%, respectively. The transparency of the hybrid structure was 10% lower than that of only Ag because of the presence of

FIGURE 3: Electrical properties of the each film on FTO glass; (a) *I-V* curve of the synthesized film and (b) the effect of UV irradiation on hybrid film (normal mode: without UV irradiation).

optically absorbing G in the hybrid structure. However, the hybrid structure exhibits a sufficiently high transparency for use in various optical devices. On the other hand, the transmittance of original PET film is 80% which is lower than others. It seems that the planarization of the rough PET surface with the hybrid coating can reduce the reflectance. The high optical transmittance of the film is attributed to refractive index matching between coating layer and the PET film and the planarization of the rough PET surface [15].

To evaluate the electrical properties of the hybrid structures, we measured the current-voltage (*I-V*) characteristics of films. These characteristics were measured using the two-probe method with an applied voltage ranging from 0 to 0.1 V supplied by a source meter (Keithley model 2400). As evident in Figure 3, all samples exhibited a linear *I-V* relationship under the experimental conditions, demonstrating their Ohmic nature. The hybridization of Ag NPs into two-dimensional G sheets enhanced the electron transfer through NP-G junctions.

We also investigated the effect of plasmonic properties of electron transfer under UV incident light (3500 mW/cm^2). To the best of our knowledge, the plasmonic properties of Ag NP-G films under UV irradiation have not been previously reported. The electrical properties of the hybrid film slightly improved under UV light compared with the properties of the same film under visible light. This effect is attributed to the Ag surface charge generated by the plasmonic effect and subsequent transfer of the generated charge to the G sheet.

Consequently, the electrical properties of the hybrid film were enhanced. Because PVP is a ligand for Ag NWs, we considered that the Ag NWs were attached to the G sheets via N-Ag bonds, which enhanced the electrical properties of the hybrid film [16].

We also investigated the effect of the hybrid structure on the efficiency of a solar cell. Films of the Ag and the hybrid material were prepared and were linked to the parallel structure of a standard solar cell. Table 1 shows the properties of the solar cell with and without UV light irradiation. The conversion efficiency was increased with Ag NPs and with the hybrid material by approximately 0.1% and 1.5%, respectively. The solar cell fabricated using the Ag-only film exhibited the same properties with and without UV irradiation. We attributed this behavior to the generated charge not transferring to the electrode because of the discontinuous structure. By contrast, in the case of the hybrid structure, the generated electron easily transferred to the electrode because of the G sheet. Thus, the G sheet provided a continuous structure for electron transfer.

4. Conclusions

In conclusion, we synthesized a facile hybrid material using PVP. The synthesized Ag-G hybrid structure exhibits high transparency and good electrical properties because of the chemical bonds between the Ag and G. This hybrid material exhibits unique properties under UV light because of the

TABLE 1: Properties of the solar cell fabricated using the hybrid structure.

	Cell type	Short-circuit voltage (Jsc, mA/cm ²)	Open-circuit voltage (Voc, V)	Fill factor (FF)	Conversion efficiency (η , %)
Solar simulator	Base cell	20	0.483	0.340	3.280
	Graphene	20	0.496	0.338	3.353
	Silver	20	0.499	0.338	3.376
	Graphene-silver hybrid	20	0.691	0.342	4.720
Solar simulator + UV lamp (240–400 nm)	Graphene	20	0.264	0.322	1.705
	Silver	20	0.529	0.342	3.614
	Graphene-silver hybrid	20	0.628	0.344	4.325

plasmonic effect of the Ag NPs. The conversion efficiency of a solar cell was increased by 1.5% when fabricated using the hybrid structure. The results of this study imply that the developed hybrid structure is potentially useful in various optical devices.

Disclosure

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Conflicts of Interest

The author declares that he has no conflicts of interest.

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