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FABRICATION OF PbS FILMS FOR AIR MASS FILTER OF SOLAR SIMULATOR

FABRIKASI LAPISAN TIPIS PbS UNTUK APLIKASI AIR MASS FILTER DI SOLAR SIMULATOR

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ABSTRAK

Saat ini, produksi panel surya terus meningkat karena meningkatnya permintaan baik di tingkat industri maupun perumahan. Hal ini juga menyebabkan meningkatnya permintaan terhadap alat pengujian panel surya, misalnya solar simulator. Solar simulator merupakan alat untuk menilai kinerja panel surya yang digunakan pada skala laboratorium dan industri. Salah satu komponen utama pada simulator panel surya adalah filter sumber cahaya (Air Mass Filter, AMF). Pada dasarnya fungsi utama AMF adalah menghilangkan pita gelombang yang tidak diinginkan yang keluar dari sumber cahaya simulator surya (misalnya lampu busur Xe) sehingga spektrum yang disaring sepadan dengan spektrum cahaya matahari. AMF dapat diproduksi dengan membuat lapisan tipis material pada substrat transparan seperti kaca. Lapisan tipis tersebut akan berperan sebagai penyerap pada pita gelombang tertentu melalui berbagai cara. Dalam makalah ini, dilaporkan pembuatan film tipis PbS kalkogenida untuk aplikasi sebagai AMF. Teknik penguapan termal (thermal evaporator technique) digunakan untuk pembuatan lapisan tipis. PbS dikenal karena keserbagunaannya untuk aplikasi pada perangkat optik yang berbeda, karena sifat optiknya yang dapat disesuaikan. Jumlah bubuk sumber PbS yang berbeda (dalam gram) digunakan untuk pengendapan film tipis PbS. Sifat optik film kemudian diperiksa menggunakan spektroskopi UV-Vis. Distribusi intensitas transmitansi lampu busur Xe dengan dan tanpa penggunaan film sebagai filter optik kemudian diperiksa menggunakan simulator surya. Dari percobaan, film yang diendapkan menggunakan sumber bubuk PbS 0,012 g dianggap paling optimal dalam hal distribusi intensitas transmitansi.

Keywords: *PbS; Thin Film; Thermal Evaporator; Chalcogenide; Solar Simulator.*

ABSTRACT

The production of solar panels is continuously increasing due to increasing demands at industrial and residential levels. This also leads to an increasing demand for solar simulator testing tools. A solar simulator is a tool to assess a solar panel's performance in lab and industry scales. One of the main components of the solar simulator is the Air Mass Filter (AMF). The primary function of AMF is to remove unwanted wave bands from the solar simulator light source (e.g., Xe arc lamp) so that the filtered spectrum is commensurate to that of solar irradiation. An AMF can be produced by fabricating a thin material layer on a transparent substrate like glass. The film would absorb certain wave bands in different ways. This paper reports the fabrication of the chalcogenide PbS thin films for applying

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AMF. The thermal evaporation technique is used for the film fabrication. PbS is known for its versatility for applications in different optical devices due to its tailorable optical properties. Different amounts (in grams) of PbS source powders are used to deposit the PbS thin films. The optical properties of the films are then examined using UV-Vis spectroscopy. The distributions of the transmittance intensity of the Xe-arc-lamp light with and without the use of the films as an optical filter are then examined using a solar simulator. From the experiments, the film deposited using a 0.012 g PbS powder source is regarded as the optimum one regarding the transmittance intensity distribution.

Keywords: *PbS; Thin Film; Thermal Evaporator; Chalcogenide; Solar Simulator.*

INTRODUCTION

The demand for a reliable and low-cost renewable energy converter, especially photovoltaic devices (solar cells), has significantly increased in the last decade. This is also in parallel with a significant increase in a photovoltaic device's maximum power. It implies an increasing need for research equipment and test apparatus in the field of photovoltaic devices, which are of scientific (and industrial) standard but still affordable. One of those tools is a solar simulator (Domínguez et al., 2008). A solar simulator is one of the standard devices used to test the performance of a photovoltaic device at both laboratory and industrial levels (Emery, 1986; Meng et al., 2011).

The device's function is to assess a solar panel's peak power and I-V curves (Presciutti et al., 2014). Practically, in its usability, a solar simulator is a device that produces artificial sunlight with wave spectrums closely approximating that of natural sunlight. This device consists of at least two main components, namely a light source (Esen et al., 2017) and a light filter commonly referred to as an air mass filter (AMF) (Sayre & Dowdy, 2010). The filter has the leading role in filtering out the wavelength bands that deviate from the natural solar spectrum by absorbing those 'unwanted' wavebands in different ways. In other words, the filter mimics the atmospheric absorbance towards the sunlight spectrum. There are some parameters of the light source to ensure a solar simulator works optimally, namely spatial, and temporal stability, uniformity, and emission spectrum. The latter depends highly on the light source and the optical filter (Presciutti et al., 2014).

Some light sources are commonly used for solar simulators, such as carbon arc (Ross & Bickler, 1963), argon arc (Petrasch et al., 2007), high-pressure sodium vapor (Li et al., 2016; Meng et al., 2011), and quartz tungsten halogen lamp (Irwan et al., 2015; Roberts et al., 2014), metal halide lamp (Codd et al., 2010), LED (Jang & Shin, 2010), and xenon (Xe) arc lamp (Bari et al., 2012; Riedel et al., 2015). Xe arc lamp is the most commonly used light source in solar simulators (Petrasch et al., 2007; Presciutti et al., 2014). It provides a continuous spectrum from UV to visible wavelengths with balanced spectral properties. Another advantage of using Xe arc-lamp as a light source in a solar simulator is its match to sunlight with high intensity and spectrum (Esen et al., 2017). Hence, this research chooses the Xe arc lamp as the light source. Despite its advantages, the Xe arc lamp has some drawbacks, such as high-power consumption (Ekman et al., 2016).

As mentioned, an AFM can be made of a thin film of a material deposited on transparent materials like glass substrates. Fabrication of a thin film for application in AMF is crucial to be able to produce a cheaper product with commensurate properties or specifications to that of the commercial (imported) one. Such a commercial AMF is very expensive. For instance, a 7 x 7 cm^2 AMF costs around $2000 (Presciutti et al., 2014).

Based on this background, the research reported in this paper aims to fabricate thin PbS layers for use as filters (AMF) for solar simulators. Within this report, the PbS thin films were fabricated on thin glass substrates to be used as an optical filter (AMF) in a solar simulator. For the thin film fabrication, the thermal evaporator technique was employed. Thermal evaporation offers a straightforward method and a relatively large deposition area on a substrate. The spatial distribution of transmittance intensity of the Xe arc-lamp in the solar simulator is measured with and without the PbS film as a filter. In other words, the research is conducted to assess the optimum amount (in grams) of PbS powder source (which might imply different thicknesses of the films), especially regarding the spatial distribution of the transmitted light intensity.

Literature review

From the literature, much research has been done on the topics of filters for optical, photonics, electronic, and chemical devices (Bei et al., 2004; Dini et al., 2016; Koller et al., 2006; Loh et al., 2014; Philip et al., 2003). However, research on the fabrication of optical filters for solar simulators, i.e., air mass filters, still needs to be completed. Presciutti et al. have tried several compounds that were known to have absorption bands close to those that need to be adjusted (Presciutti et al., 2014). For example, is an absorbent mixture of 1,4,8,11,15,18,22,25-octabutoxy-29H,31H-phthalocyanine, and several poly squaraines, which has an absorption band at λ of around 1000 nm commensurate to that of need for this application. As demonstrated, the mix of the material works well in which the absorption bands of the material match what is required in the application as AMF for solar simulators. However, the material consists of a polymer, which tends to be lower in thermal and mechanical strength and prone to photodegradation during operational times, resulting in inaccurate measurement results.

In this context, an inorganic material could provide a suitable solution since it is more stable regarding thermal and mechanical properties. A metal-chalcogenide is an excellent candidate to use as AMF of solar simulators since it has been used in various optical devices and is suitable for the application's requirements as AMF. Examples are metal chalcogenides such as Lead Sulfide (PbS). PbS is a semiconductor metal-chalcogenide compound with modulable optoelectronic properties, which makes it suitable for applications in various devices such as infrared detectors (Rohom et al., 2017), gas sensors (Burungale et al., 2016), and others. In photovoltaic devices (Günes et al., 2007), PbS is usually an absorber in the solar cell (Sahadevan et al., 2022). PbS is an essential material in optoelectronic and energy devices. PbS possesses a Bohr radius of 9 nm and a bandgap of 0.41 eV at 300 K (Agnese et al., 2018). It has a rocksalt crystal structure of FCC and a molar density of 239.30 g/mol. Several deposition techniques can fabricate this semiconductor thin film in a polycrystalline phase. One of the simplest ones is using thermal evaporation (Leary et al., 2016; Sayre & Dowdy, 2010).

Moreover, recent studies showed that by modulating the crystallite sizes of chalcogenide PbS, the absorption peak could be modulated from infrared to visible and near-infrared regimes (Popa et al., 2006). Moreover, another interesting result was also shown in which the bandgap can be tuned by modulating the PbS nanocrystal sizes (Lee et al., 2016). The solid quantum confinement effect in the PbS nanoclusters allows tuning of the edge optical absorption from the IR region to the UV-Vis region, causing significant changes in its optical properties across the spectrum. Those results show the promising potential of the chalcogenide materials for applying AMF in solar simulators.

METHOD

Prior to the deposition of the film, each of the glass substrates was cleaned using freshly prepared acetone, detergent solution, and then distilled water, respectively, in the ultrasonic bath. PbS films have been fabricated using the thermal evaporation technique in the vacuum of $\leq 1\times10^{-4}$ Pa. The films were deposited on a soda-lime glass substrate placed directly above the source material at a distance of 8 cm. Each deposition took place at RT, using current and voltage of 80 A and ~1V, respectively, for evaporating the powder source.

Three thin film samples were deposited using the thermal evaporator using 0.006, 0.012, and 0.018 g of PbS powder source, respectively. After the film's deposition, the optical properties of each film were measured, namely the intensity distribution of the Xe arc-lamp radiation, which was spatially measured using the Xe-arc-lamp-incorporated solar simulator. This measurement was done to get the distribution information of the transmitted Xe arc-lamp radiation across the lateral (x-y) directions with and without the filters. The filter here means the deposited PbS films.

Firstly, the Xe-arc-lamp radiation lateral intensity distribution was measured directly without the filter. Then, the same procedure was done, however, by using the PbS film as a filter placed in between the radiation source and the photodetector. UV-Vis measurement was also performed on each sample, with the wavelength ranging from 300 to 1000 nm.

RESULTS AND DISCUSSION

As written in the experimental (Method) section, the thermal evaporations were done using three different masses of the PbS powder as the source, namely 0.006, 0.012, and 0.018 g. Figure 1a-c shows the three different groups of films: 0.006, 0.012, and 0.018 g, respectively. As seen from the figures, the higher the amount of the PbS powder source being used, the darker the visibility of the films, which indicates the thicker the film deposited. However, the thickness of the films is still to be measured.

As explained, a solar simulator set has measured the distribution of the transmitted Xe arc-lamp radiation intensities with and without using any PbS thin films as a filter. Figure 2a shows the distribution of the transmittance intensities of the Xe arc-lamp radiation without any filter, while Figure 2b-d shows that using PbS thin films as a filter. The three films to be used as the filters are deposited using 0.006, 0.012, and 0.018 g of PbS powder as the deposition source, respectively. In the figures, the x- and y-axis correspond to the lateral dimension of the Xe beam (across the filter surface when a thin film filter is used). In contrast, the z-axis corresponds to the intensity of the transmitted Xe beam.

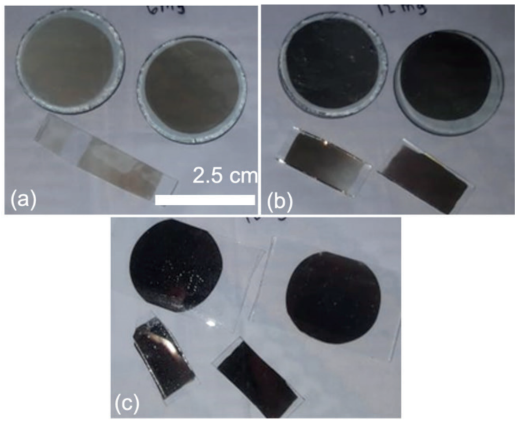

Figure 1.
The deposited PbS thin films using the thermal evaporator with different masses of PbS source powder of (a) 0.006 g, (b) 0.012 g, and (c) 0.018 g.
Source: Researcher documentation

Figure 2a shows that the bare-Xe-arc-lamp light intensity is not uniform across the radial (x-y) directions. There is a decrease in intensity at the circular edge regions, making the whole spectrum a wide-mound-like 3D spectrum. Figure 2b shows the transmitted Xe arc-lamp light intensity using the filter of PbS-0.006-g film. The figure shows that the intensity distribution has changed compared to that in Figure 2a.

The peripheral intensities have been 'truncated' by the 0.006 g PbS film, while only the central intensity remains. This central intensity is still relatively high, similar to the central intensity in Figure 2a. The root cause of this central peak intensity needs to be clarified. First, we must remember that the source light is also peaking at the center, so a non-homogeneity of the layer is one possible cause. However, it is a weak possibility since a film's non-homogeneity logically occurs in the lateral direction but not in the radial dimension. If that is the case (in a circular direction), then the center of the sample should be the thickest part compared to the peripheral regions, not the other way around.

Figure 2c shows the transmitted intensity when a 0.012-g-PbS filter is used. The figure shows that, in addition to the peripheral intensities that have been removed, the central intensity has been truncated as well so that the whole distribution tends to be flatter than that of Figure 2b. Also, to note, the average intensity is around 1000 W/m^2 (in the grey-coloured region), which is desirable to the application for the AMF 1.5 G. Figure 2d shows intensity of the 0.018-gr-PbS filter, in which the global intensity has been truncated even more, where almost all grey area (middle intensity) is removed, and only lower intensity remains. This might indicate that the film is too thick, which makes the average intensity too low, which is not ideal for applying AMF 1.5 G.

From these results (Figure 2a-d), we can assess that the 0.012 g-film has the optimum transparency distribution compared to the other two films. The assessment is based on the transmitted intensity of the 0.012 g-film, which is the most uniform across the lateral area of all the other films. For the 0.006 g-film, the solid central peak is undesirable in the filter application since the more uniform the intensity across the lateral surface of the filter, the more desirable it is.

The transmitted intensity needs to be higher for the thicker film (0.018 g-film). A lower transmitted intensity is also not desirable because for testing the performance of the photovoltaic device, the higher intensity means, the more precise a measurement could be performed. From the trend in Figure 2a-c, global intensity decreases from 0.006-gr-PbS to 0.018-gr-PbS films. This makes sense since the higher amount of Pb powder source is evaporated, meaning the thicker the film could be produced.

Figure 3 shows the absorption spectrum of the PbS thin films. From the figure, each of the PbS thin layers has an absorption peak at UV wavelengths and has a relatively low absorption in the visible range, and there is an increased absorption at NIR wavelengths. This is suitable for an air mass filter application, i.e., to filter excess UV and IR radiation bands generated by the Xe arc lamp as the light source in a solar simulator. From these spectra, it can also be seen that the thicker the PbS layer, the higher the absorption in the wavelength range 300 – 1000 nm. In this case the 0.018 g sample absorbed the highest intensity compared to the 0.012 g and 0.006 g samples. It is understandable since the thicker the film, the more material it is to absorb the intensity.

However, as mentioned, the absorption band of each film shares the same trend. In other words, there is no change in the absorption band about the film thickness.

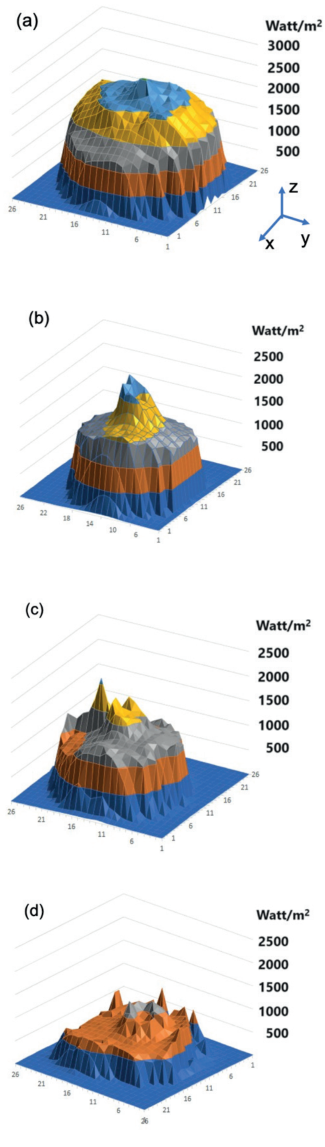

Figure 2.
Distribution of the transmitted Xe-arc-lamp light intensities across the lateral direction of the PbS film: (a) without the use of any filter, and with PbS thin film deposited using (b) 0.006 g, (c) 0.012 g, and (d) 0.018 g of PbS powder sources, respectively, positioned in between the light source and the detector. Each pixel corresponds to 2 mm x 2 mm area.
Source: Experimental Data analysis

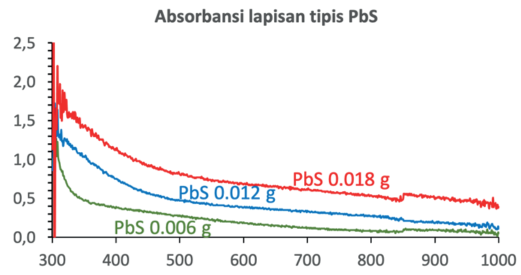

Figure 3.
Absorbance of the PbS thin layer in the UV-Vis-NIR wavelength range of 300-1000 nm.
Source: Experimental Data analysis

CONCLUSION

The need for low-cost solar panels requires lower fabrication costs and lower-cost photovoltaic device test apparatus such as solar simulators. One component of a solar simulator is an air mass filter (AMF). So far, the price for a commercial (exported) AMF is very high. Hence, fabricating a lower-cost AMF is necessitated.

The research focuses on fabricating PbS thin films to apply an AMF for solar simulators. The films were fabricated using the thermal evaporator technique using different amounts (in grams) of PbS powder source. The films were measured using UV-Vis spectroscopy to investigate the optical absorption of the films. The UV-Vis measurements show no evidence of different absorption bands between the films within the spectrum range. In other words, the thickness of the films does not influence the optical absorption band, yet only affects the absorption intensity.

A solar simulator using an Xe arc lamp was used to see the distribution of the transmitted light intensity across the film surface laterally. To conclude, the experiment on finding the optimum thermal evaporation parameters for finding the optimum amount of the PbS powder target (the mass of the PbS powder target) has been performed during the thermal evaporation process of PbS films. According to the AMF 1.5 G target at an intensity of 1000 W/m^{2,} the optimum film was found to be the film deposited using 0.012 grams of PbS powder.

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