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Muscovite Potential as Flexible Substrate for High-Temperature Photovoltaic Process

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Abstract. *The exploration of muscovite as a flexible substrate that withstand high-temperature photovoltaic processes presents a promising avenue for advancing solar energy technologies. Muscovite, a naturally occurring mica mineral, exhibits exceptional thermal stability, mechanical flexibility, and chemical inertness, making it an ideal candidate for photovoltaic applications that require high-temperature processing. This study investigates the structural and decomposition properties of muscovite, emphasizing its potential to withstand the rigorous conditions of photovoltaic fabrication. Through a series of experimental analyses, including thermal gravimetric analysis (TGA), X-ray diffraction (XRD), and Atomic force microscopy (AFM), we demonstrate that muscovite maintains its integrity and performance at process temperatures exceeding 500°C. The findings suggest that muscovite supports high-temperature processes. This research underscores the viability of muscovite as a flexible, high-temperature substrate, paving the way for innovative advancements in solar energy harvesting and utilization.*

Keywords: *muscovite, flexible, photovoltaic*

1. Introduction

The quest for efficient and sustainable energy sources has driven significant advancements in photovoltaic (PV) technologies. Solar energy, being abundant and renewable, stands at the forefront of these efforts. However, the efficiency and durability of photovoltaic devices are often constrained by the materials used in their construction, particularly the substrates that support the active layers. Traditional substrates, such as glass, metal foil, and silicon, while effective, present limitations in terms of flexibility and thermal stability. This has spurred research into alternative materials that can withstand high-temperature processes and offer mechanical flexibility, thereby enhancing the performance and application range of photovoltaic devices. Therefore recent studies has emerged on utilizing polymers such as Polyethylene terephthalate (PET) (Faraj et al., 2011), Polyimide (PI) (Caballero et al., 2011; Koo et al., 2020; Park et al., 2017; Romeo et al., 2006), Polyethylene naphthalate (PEN) (Skafi et al., 2023; Zhu et al., 2019) for flexible substrates. However, its low thermal stability limits their use in high-temperature processes.

Muscovite, a naturally occurring mica mineral, emerges as a promising candidate in this context. Known for its exceptional thermal stability, mechanical flexibility, and chemical inertness (Bitla & Chu, 2017; Yen et al., 2019), muscovite offers a unique combination of properties that are highly desirable for high-temperature photovoltaic processes. Unlike conventional substrates, muscovite can endure extreme temperatures without degrading, making it suitable for advanced PV fabrication techniques that require high thermal processing.

This study aims to explore the potential of muscovite as a flexible substrate for

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high-temperature photovoltaic applications. By investigating its structural and thermal decomposition properties, we seek to establish muscovite's viability in supporting the rigorous conditions of PV device fabrication. The research encompasses a comprehensive analysis of muscovite's performance under high temperatures, utilizing techniques such as thermal gravimetric analysis (TGA), X-ray diffraction (XRD), and Atomic force microscopy (AFM). These methods provide insights into the material's stability, structural integrity, and compatibility with various photovoltaic materials.

Furthermore, the mechanical flexibility of muscovite opens new avenues for the development of flexible and lightweight photovoltaic devices. Such devices are not only easier to install but also expand the possibilities for solar energy applications in various fields, including wearable technology, portable power sources, and building-integrated photovoltaics (BIPV). The combination of high thermal stability and flexibility positions muscovite as a versatile substrate that can meet the evolving demands of modern photovoltaic technologies. In addition to its practical advantages, the use of muscovite aligns with the broader goals of sustainability and environmental responsibility. As a naturally abundant mineral, muscovite offers an eco-friendly alternative to synthetic substrates, reducing the environmental impact of PV device manufacturing. This aspect is particularly relevant in the context of the global push towards greener technologies and the reduction of carbon footprints.

The findings of this study are expected to contribute significantly to the field of photovoltaic research, providing a foundation for further exploration of muscovite and similar materials. By demonstrating the feasibility and benefits of using muscovite as a high-temperature, flexible substrate, this research paves the way for innovative advancements in solar energy harvesting and utilization. The potential applications of muscovite-based PV devices are vast, ranging from traditional solar panels to cutting-edge flexible electronics, highlighting the material's versatility and importance in the future of renewable energy technologies. This study underscores the material's unique properties and potential applications, offering a promising pathway for the development of next-generation photovoltaic devices. As the demand for sustainable energy continues to grow, the integration of innovative materials like muscovite will be crucial in meeting the challenges and opportunities of the renewable energy landscape.

2. Method

Natural muscovite substrate with thickness 25 µm was cut into 2x2 cm and cleaned in DI water followed by ethanol using ultrasonic cleaner. An 800 nm thick Mo (99.99 wt%) back contact layer was deposited via DC-magnetron sputtering under an Ar pressure of 3sccm on the substrate. Prior to Mo sputtering, an adhesion layer of TiN (99.5 wt%) was deposited using DC magnetron sputtering under an Ar pressure of 5 sccm. Mo film on muscovite without adhesion layer is used as reference sample.

The stability of muscovite under different temperature was analyzed by thermal gravimetric analysis (TGA). The topography of mica surfaces was examined through atomic force microscopy Bruker. Crystal structures of Mo films were analyzed via X-ray diffraction (XRD) with Cu-Kα radiation using a SHIMADZU XRD-7000.

3. Results and Discussions

The Thermal Gravimetric Analysis (TGA) of muscovite was conducted to evaluate its thermal stability and decomposition behavior under high-temperature conditions. The TGA curve, as shown in Figure 1, which plots the residual mass percentage against

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temperature, provides critical insights into the material's performance. The TGA curve for muscovite shows two significant weight loss events at approximately 570°C and 787°C. These events correspond to the decomposition of muscovite's structural components. The initial weight loss occurred around 570°C can be attributed to the dehydroxylation of muscovite. Dehydroxylation is the process where hydroxyl groups (OH-) are removed from the mineral structure, resulting in the release of water (H_2O) (Cheng et al., 2019). This is a common phenomenon in mica minerals and indicates the breakdown of the hydroxyl bonds within the muscovite structure. The second weight loss (at 787°C) is likely due to the decomposition of the muscovite's silicate framework. At this temperature, the breakdown of the aluminosilicate structure occurs, leading to the release of volatile components and a significant reduction in mass. This indicates the thermal limits of muscovite, beyond which its structural integrity is compromised.

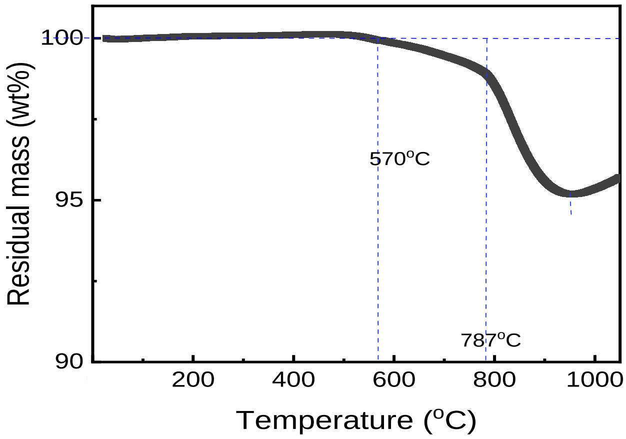

Figure 1. Thermal gravimetric analysis result of muscovite

The residual mass at the end of the TGA analysis remains relatively stable after the second weight loss event. This stability suggests that muscovite retains a portion of its structure even at high temperatures, highlighting its potential as a high-temperature substrate. The remaining mass is likely composed of more thermally stable components that do not decompose within the tested temperature range. This indicates that muscovite can endure prolonged exposure to high temperatures without significant degradation. The ability to withstand temperatures up to 787°C without complete decomposition is particularly advantageous for photovoltaic fabrication techniques that require high thermal processing.

Figure 2 shows the XRD spectra of muscovite. The X-ray diffraction (XRD) spectra of muscovite typically exhibit distinct *(00l)* peaks corresponding to its crystalline structure, indicating the presence of well-defined crystallographic plane. Muscovite, a phyllosilicate mineral, is characterized by its layered structure, which is reflected in its XRD pattern. The sharp and intense peaks correspond to the (006), (0010), and higher-order reflections, which are characteristic of the well-ordered layered structure of muscovite. This high crystallinity is beneficial for photovoltaic applications as it ensures consistent and predictable material properties. The layered nature of muscovite contributes to its mechanical flexibility. The weak van der Waals forces between the layers allow for easy bending and flexing, making muscovite an excellent candidate for flexible substrates in solar cells.

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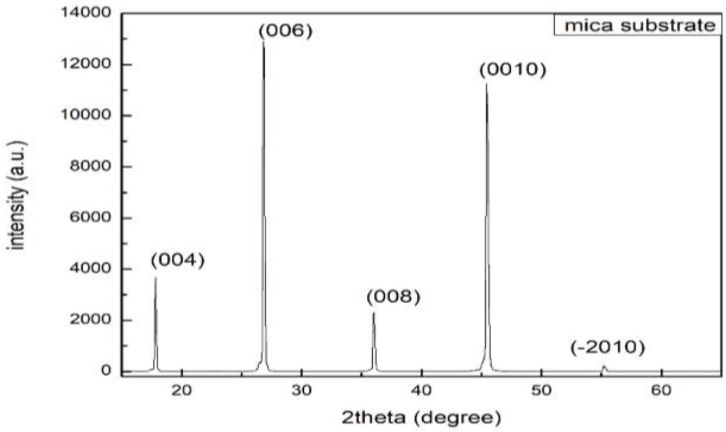

Figure 2. XRD spectra of fresh muscovite

To observe the topography of muscovite surface, AFM was used. The results are presented in Figure 3. The AFM image of muscovite shows a relatively smooth surface with occasional steps and terraces. The average surface roughness is 144 pm. The topography before (Figure 3a) and after annealing (Figure 3b) at temperature 550ºC experienced no significant changes. The uniform surface topography of muscovite ensures consistent deposition of photovoltaic materials.

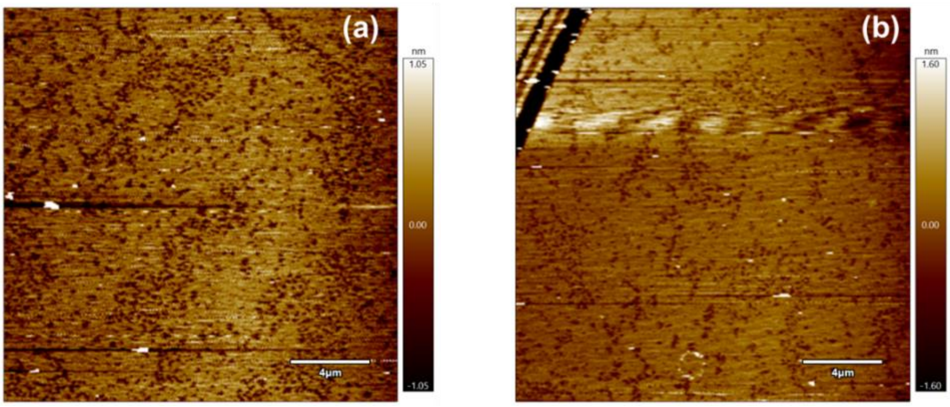

Figure 3. The topography of muscovite surface: (a) before and (b) after annealing at temperature 550ºC

4. Conclusions

Muscovite performs robust thermal stability and decomposition behavior, making it a promising candidate for high-temperature photovoltaic applications. Its high crystallinity and well-ordered layered structure contribute to mechanical stability as flexible substrate. Furthermore, a smooth and uniform muscovite substrate is essential for achieving high-efficiency solar cells, as it minimizes defects and irregularities that can affect the performance of the active layers. This early study will be benefits as utilizing mica for flexible substrate that demand high temperature solar cell fabrication process.

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