

Morphology Evolution of Snow-flakes Pattern and its Effect on Nano-/Micro-particles Embedded PbSe Photoconductive Thin Film Characteristics

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Summary:

This study focuses on optimizing the fabrication of mid-wavelength infrared (MWIR) PbSe photodetectors, widely used in commercial, medical, environmental, industrial, and military applications due to their reliable, cost-effective performance at room temperature. Using chemical bath deposition (CBD), we identified unique snowflake-like patterns on PbSe surface, containing embedded nano-prisms. These formations are linked to PbSe recrystallization during the oxygen sensitization process. The research examines how these patterns evolve—forming, expanding, and eventually reducing—under varying oxygen exposure times and temperatures. Optimal detector performance is observed when snowflake density is highest, as indicated by enhanced photoluminescent (PL) output. Beyond a specific threshold, however, increased temperature leads to a reduction in pattern size and a decline in performance. By employing spectroscopic (PL/FTIR, UV-Vis) and structural (XRD, XPS, Hall-effect) analyses, the study demonstrates that snowflake morphology serves as a visible marker of ideal CBD conditions for producing high-sensitivity PbSe photoconductive detectors.

Keywords: lead selenide, photoconductive detector, nano-particle, nano-prism, snowflakes, sensitivity, responsivity, photoluminescent, sensitization, chemical bath deposition (CBD).

Introduction

Mid-wavelength infrared (MWIR) lead selenide (PbSe) detectors, produced via chemical bath deposition (CBD), have become essential in various commercial fields, including environmental monitoring, industrial sensing, medical diagnostics, and military applications. These detectors are favored for their reliability, cost efficiency, and effective room-temperature operation, making them an ideal solution for diverse sensing needs. Recent studies have highlighted the formation of distinctive snowflake-like patterns on PbSe active layer during oxygen sensitization. These patterns, containing embedded nano- and micro-particles—primarily nano-prisms—are thought to serve as visible indicators of PbSe recrystallization, reflecting crucial changes in detector properties and signaling optimal fabrication conditions.

In this work, we build upon previous research by introducing a novel approach to develop nanostructured PbSe thin-film photoconductive detectors [1], using snowflake patterns on the active region as observable markers for the crystallization process [2-3]. By systematically

examining the formation and evolution of these patterns under varying oxygen sensitization conditions, we establish a clear correlation between snowflake morphology and detector performance. The characterization of these patterns and their effects on device functionality was carried out using spectroscopic techniques (PL/FTIR and UV-Vis) alongside structural analyses (XRD, XPS, and Hall-effect measurements). These methods confirm that snowflake density serves as a practical indicator for optimizing CBD conditions, advancing the development of high-performance PbSe detectors.

Results and Discussion

The results reveal key aspects of the snowflake-like pattern formation and its correlation with the performance of PbSe photodetectors. Figure 1(a) presents the initial appearance of snowflake patterns on the PbSe active surface, while Figure 1(b) highlights clusters of nano- and micro-particles beneath the snowflakes. Figure 2 shows the progression of snowflake patterns as a function of oxygen sensitization time at 415 °C, where the patterns first emerge, expand, and then reduce in size with prolonged

annealing. After wet-etching, Figure 3 reveals the active surface after removing the PbSe oxide phase, providing clearer insight into the pattern structure.

In Figure 4, snowflake development is depicted across different oxygen sensitization temperatures, showing a direct relationship between snowflake population density and the detector's signal response. This trend is further supported by the photoluminescent (PL) data in Figures 5 and 6, which demonstrate that shorter annealing times produce stronger PL signals at elevated temperatures, such as 415 °C, particularly at a wavelength of 4.0 μ m. Figure 7 shows the FTIR spectra (relative responsivity) of a 1x1 mm² PbSe detector at room temperature, indicating a peak in responsivity that coincides with optimized snowflake morphology.

Conclusion

In conclusion, the snowflake patterns observed on the active area of the PbSe detector represent a recrystallization phenomenon, serving as a visible and reliable indicator of detector quality. This morphology directly correlates with optimized chemical bath deposition (CBD) conditions, enhancing photodetector sensitivity and providing a straightforward, cost-effective approach to advancing high-performance MWIR PbSe detectors for commercial applications.

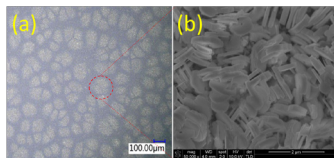


Fig. 1. A microscope photo showing the snowflake patterns (a) and a SEM image of nano-/micro-particles formed beneath them (b).

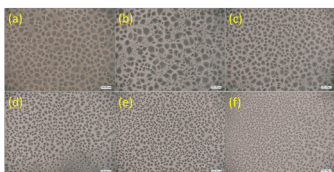


Fig. 2. Microscope images as a function of oxygen sensitization time at 415 °C. (a) 1min, (b) 2.5min, (c) 5min, (d) 7.5min, (e) 15min, and (f) 20min.

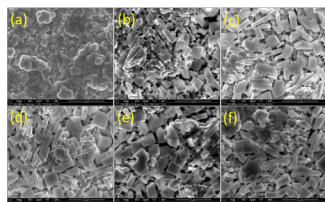


Fig. 3. SEM images showing the site of the evolution of nano-/micro-particles embedded PbSe thin film beneath snow-flakes pattern as a function of oxygen sensitization time. (a) 1min, (b) 2.5min, (c) 5min, (d) 7.5min, (e) 15min, and (f) 20min.

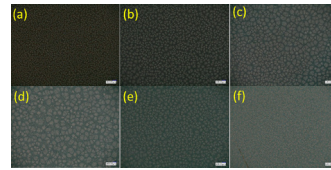


Fig. 4. Microscope photos showing the evolution of the snowflake patterns as a function of annealing temperature in oxygen atmosphere. (a) 350°C, (b) 380°C, (c) 390°C, (d) 400°C, (e) 410°C, (f) 430°C.

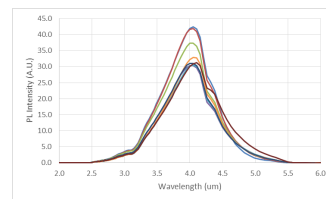


Fig. 5. PL spectra variation as a function of oxygen sensitization time with fixed 415 °C temperature.

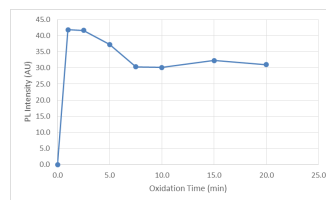


Fig. 6. PL intensity change as a function of oxygen sensitization time at $\lambda=4.0\mu$ m at 415°C temperature (corresponding to Fig. 2).

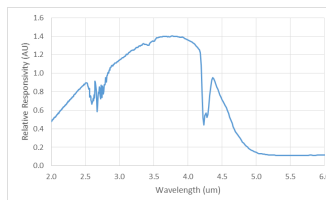


Fig. 7. Typical Sensitivity (Relative Responsivity) at 300K for 1x1mm² PbSe Detector with 5V DC supply.

References

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