

Enhancement of Hybrid Radiation Detector Characteristics through Size Control of MoS₂ Nanocrystals

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In recent semiconductor scaling, encountering physical limits, 2D materials are gaining significant attention. Among them, TMDs and MXenes are actively researched as 2D materials due to their superior electrical conductivity and physical stability compared to graphene. Among TMDs, MoS₂ is bound by Van der Waals forces, allowing easy separation into individual sheets using sonification, and it has the advantage of being able to adjust the Bandgap according to the number of 2D layers. Furthermore, as MoS₂ approaches 2D, it becomes mechanically flexible and exhibits a Direct Bandgap, with the advantage of a wider photoactive region compared to Si or GaAs. This study developed a radiation detector with an organic/inorganic hybrid active layer using MoS₂ nanocrystals of various sizes obtained through ultrasonic exfoliation and centrifugal separation processes, as illustrated in Fig 1a. TEM images of MoS₂ nanocrystals obtained at each rpm in Fig. 1b-e show that as the centrifugation speed increases, the size decreases. The TEM image of MoS₂ nanocrystals obtained at 8000 rpm in Fig 1f confirms that even as the size decreases, the 2D characteristics of MoS₂ nanocrystals are maintained.

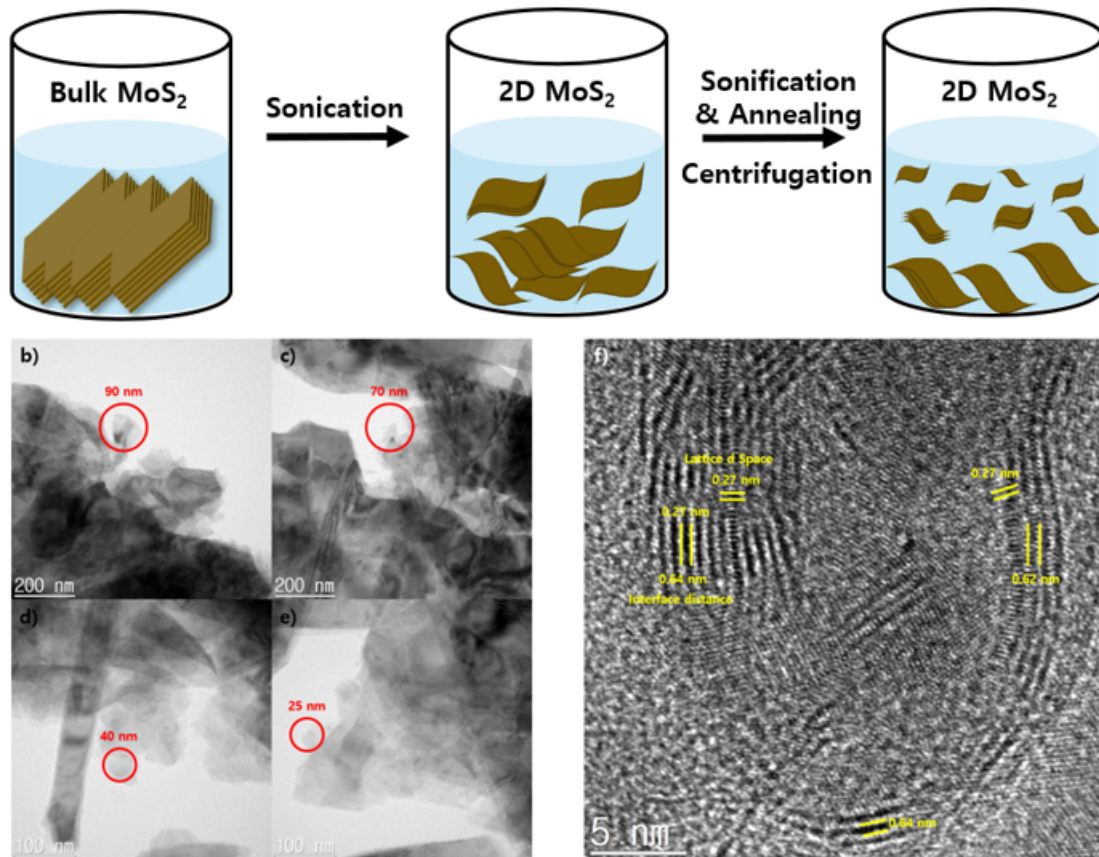


Figure 1: (a) Ultrasonic exfoliation and centrifugal separation process for MoS₂ nanocrystals, HRTEM images of MoS₂ nanocrystals with centrifugation distribution (b) 2000 rpm, (c) 4000 rpm (d) 6000 rpm (e) 8000 rpm (f) HRTEM image of MoS₂ layer to show the lattice fringes

The organic material used in the experiment is P3HT:PCBM, and to assess the effect of MoS₂ size variations, the mixing ratio of MoS₂ was fixed at 3 wt% for the experiments. Figure 2 shows the corresponding energy

levels of the proposed detector and the process of charge collection.

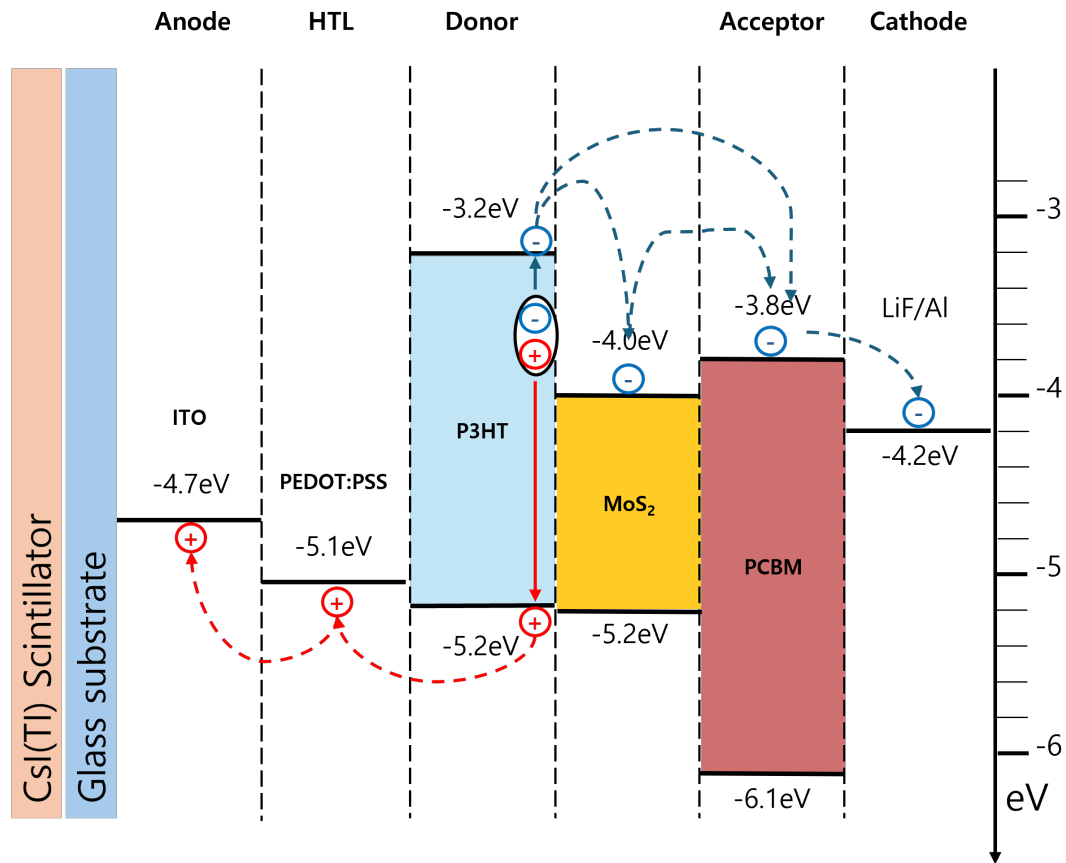


Figure 2: The energy band diagram of the indirect X-ray detector

Fig 3 shows the parameters of the radiation detectors for samples according to the size of MoS₂ used in active layer. The developed radiation detector demonstrates optimized results at 8000 rpm, showing a 34% improvement in sensitivity compared to detectors without MoS₂ in the active layer.

| Sample | MoS ₂ Size [nm] | DCD [nA/cm ²] | CCD [nA/cm ²] | Sensitivity [mA/Gy*cm ²] |
|--------|----------------------------|---------------------------|---------------------------|--------------------------------------|
| a) | - | 0.313 | 153.659 | 1.145 |
| b) | 90 | 0.328 | 180.263 | 1.345 |
| c) | 70 | 0.389 | 187.152 | 1.394 |
| d) | 35 | 0.455 | 195.56 | 1.456 |
| e) | 25 | 0.564 | 207.16 | 1.542 |

Figure 3: Parameters of developed X-ray detectors a) Active layer without MoS₂ nanocrystals, b-e) Active layer with 3 wt% MoS₂ nanocrystals obtained at 2000, 4000, 6000, 8000 rpm

Our results indicate that the use of 2D MoS₂ nanocrystals is a promising approach to enhance the properties of semiconductor materials, suggesting its applications in a wide range of fields including electronics and optoelectronics engineering.

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