**Progress on Characteristically Induced Proton-Irradiated 2DMs: A Compassed Review**

Joseph Francis Razon  
Department of Chemical Engineering  
Pennsylvania State University

**Introduction**

- This project explores the progress made on proton-irradiated two-dimensional materials (2DMs).
- It was intended to be a compass to guide current researchers in the field to what can be done next.

**Significance**

- 2DMs act as a promising candidate for space applications due to their unique characteristics such as band gap tunability, high carrier mobility, thermal conductivity.
- Hydrogen ions (protons) fall into limitation barriers that silicon-based equipment present.
- New alternatives must be explored to prevent protons and other heavy charged particles from damaging vitals.

**Methodology**

- Priority was given to the effects of proton irradiation on mono- or multi-layered samples
- Key displacement damage mechanisms and effects are presented qualitatively
- Data on laser fluency, dosage, thickness of material, irradiation source, general optical methodology, impact/defect information, along with references, was tabulated based on material

**Summary**

- MoS$_2$: studies showed alteration of sideband peaks, number of defect sites, dia/para/ferro magnetic responses, and electrical characteristics
- WSe$_2$: studies presented altered electrical properties (current/threshold voltage) and enhanced discharge capacity/cyclability
- Graphene: studies showed increased defect sites, cross sectional damage, and change of structural properties on the atomic scale

**Future Outlook**

- Number of proton-radiation hard materials seems to be continuously increasing
- MoS$_2$, FET's unique electronic properties and graphene's lightweight structure, prove to be a potential candidate for space applications
- Current investigations should expand to other 2DMs such as W$_2$S, MoSe$_2$, HBN, and WTe$_2$

**Acknowledgments**

I am grateful for the wonderful opportunity that MC REU presented me this summer, along with Christina Riehman for her invaluable literature guidance, and especially Dr. Burcu Ozen who has supported me with her many years of research experience.

**References**

1. m02-crystal_structure_2048x2048_PNG (2048x2048). (n.d.). Retrieved July 24, 2020, from https://doi.org/10.2417/2048x2048_PNG

---

**Table 1. Partially Shown MoS$_2$ Tabulated data.**

<table>
<thead>
<tr>
<th>Energy</th>
<th>Thickness</th>
<th>Fluence Range</th>
<th>Impact/Defect</th>
<th>Irradiation Source</th>
<th>General Method(s)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 keV</td>
<td>monolayer</td>
<td>10$^{14}$ to 10$^{15}$ cm$^{-2}$</td>
<td>created defect-induced sideband peak at 1.7 eV and decrease in PL Intensity by 2.8X factor</td>
<td>LEAF</td>
<td>PL/AFM/AFM/Raman</td>
<td>[38,42]</td>
</tr>
<tr>
<td>10 MeV</td>
<td>crystal</td>
<td>10$^{14}$ to 10$^{15}$ P/cm$^2$</td>
<td>n/a</td>
<td>AFM/TEM/SERRIM</td>
<td>[13]</td>
<td></td>
</tr>
<tr>
<td>100 keV</td>
<td>Bi/Te/Multi Layered</td>
<td>6 x 10$^{14}$ to 6 x 10$^{15}$ P/cm$^2$</td>
<td>increases intensity up to 6E14 cm$^{-2}$/sec; decreases at higher fluences</td>
<td>LEAF</td>
<td>PL/TEM/STEM/SERRIM/TEM</td>
<td>[43]</td>
</tr>
</tbody>
</table>

**Figure 1. Atomic Structure (left) & optical/fluorescent picture (right) of MoS$_2$ & 2D-Mo$^2+$ [1].**

**Figure 3. Graphene p-doping due to upward G/2D peak shift [3].**

**Figure 4. MoS$_2$ Magnetism vs field measurements [4].**

**Figure 5. MoS$_2$ FET Voltage vs Current [2].**

**Figure 6. TEM pictures of nanopores on Graphene-MT on (left) Cu and (right) Ni substrate [5].**

**Figure 7. Raman spectra (left) and XPS spectra (right) of WS$_2$ flakes before and after irradiation [6].**