

Research project summary report for prospective PhD candidates

Title of the project: Flexible devices based on 2D semiconductor for low-cost IoT and Industry 4.0 sensors (FLEX2D)

General objective:

The FLEX2D project aims to revolutionize flexible electronics by leveraging van der Waals semiconductors integrated with flexible supports. Utilizing an innovative high-throughput mechanical exfoliation technique, the project seeks to produce large-area films of interconnected flakes at a fraction of the cost of traditional methods, while maintaining high electronic performance. These films will be used to fabricate various electronic components, such as transistors and phototransistors, which will be integrated into complex systems like logic circuits and basic camera sensors.

Specific objectives:

1. **High-throughput exfoliation technique development:** Optimize the high-throughput mechanical exfoliation technique for cost-effective large-area films production of van der Waals semiconductors, insulators, and conductors.
2. **Flexible electronics fabrication protocols:** Develop protocols for fabricating electronic devices from transferred van der Waals films, addressing challenges with flexible and stretchable substrates.
3. **Performance characterization:** Conduct comprehensive characterization of exfoliated films and devices using advanced techniques to assess electronic and optoelectronic properties and correlate macroscopic device performance with microscopic variability.
4. **Integration into complex systems:** Fabricate and integrate transistors and photodetectors into sophisticated systems, including logic circuits and arrays of photodetectors for flexible spectrometers and camera sensors.
5. **Flexibility assessment:** Characterize the fabricated devices under various degrees of substrate bending using specialized apparatus to measure applied strain accurately.

Track record of the research team:

Dr. Andres Castellanos-Gomez:

- Globally recognized leader in 2D materials.
- Consistently recognized among 'Highly Cited Researchers' (2018–2022).
- ERC-StG grant recipient, demonstrated first straintronic photodetector device.
- Awards: National Research Award (2022), Miguel Catalan Scientific Award (2022), Young Experimentalist Researcher Award (2016).
- Over 27,000 citations (h-index 71).

Dr. Carmen Munuera:

- Specialist in nanoscale functional characterization of materials.
- Leading the Scanning Probe Microscopy (SPM) laboratory at ICMM.
- Extensive research in layered materials and numerous national and international projects.
- Awards: Young Scientist Award from the Royal Science Academy of Sevilla (2011).
- Over 100 peer-reviewed publications (3,000 citations, h-index 30).

Material and equipment resources:

FLEX2D team members will have access to state-of-the-art infrastructure for fabrication and characterization of electronic and optoelectronic devices at the 2D Foundry research group and shared facilities at ICMM-CSIC and UAM-CSIC. This includes:

- **Device fabrication infrastructure:**
 - Micro-fabrication lab with wet-bench, photolithography, thermal evaporator.
- **Isolation and characterization of 2D materials:**
 - Multiple homebuilt micro-reflectance setups, Raman+PL microscope, atomic force microscopes, and deterministic transfer setups.
 - Access to shared facilities for scanning electron microscopy, IR spectrometry, and X-ray diffractometry.
- **Characterization of devices:**
 - Atmospheric and high vacuum probe stations, cryogenic optical and electrical measurement stations, scanning photocurrent microscope, and physical property measurement systems.

Training program:

The PhD student will be hosted by the 2D Foundry research group at ICMM-CSIC, enrolling in the Doctorate Program in Physics of Condensed Matter, Nanoscience, and Biophysics at UAM. The training program includes:

- **Academic and scientific training:**
 - Integration into a dynamic, multidisciplinary group with access to cutting-edge facilities and techniques.
 - Hands-on experience through custom-designed strategies and home-made setups.
 - Participation in courses, workshops, and summer schools.
- **Transversal activities:**
 - Engagement in activities like 'Jornadas para doctorandos del CSIC' and 'Buenas Prácticas Científicas.'
- **Outreach activities:**
 - Participation in regular school visits and initiatives like 'Toca la Ciencia' and 'Ciencia en el Barrio.'
- **International collaboration:**
 - Short stay at a foreign institution (e.g., with Prof. Gianluca Fiori) to learn alternative fabrication approaches.