



**PhD Thesis Defense NICOLAS  
MORELL BENNASSER  
'Optomechanical resonators based on  
transition metal dichalcogenide  
monolayers'**

NICOLAS MORELL

December 17, 2018

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PhD Thesis Defense, December 17, 2018, 12:00. ICFO Auditorium

**NICOLAS MORELL**

Quantum NanoMechanics

ICFO-The Institute of Photonic Sciences

Suspended monolayer transition metal dichalcogenides (TMD) are membranes that combine

ultralow mass and exceptional optical properties, making them intriguing materials for opto-mechanical applications. However, the low measured quality factor of TMD resonators has been a roadblock so far. In this thesis, we first show an ultra-sensitive optical readout of monolayer TMD resonators that allows us to reveal their mechanical properties at cryogenic temperatures. We find that the quality factor of monolayer WSe<sub>2</sub> resonators greatly increases below room temperature, reaching values as high as 16000 at liquid nitrogen temperature and 47000 at liquid helium temperature. This surpasses the quality factor of monolayer graphene resonators with similar surface areas. Upon cooling the resonator, the resonant frequency increases significantly due to the thermal contraction of the WSe<sub>2</sub> lattice. These measurements allow us to experimentally study the thermal expansion coefficient of WSe<sub>2</sub> monolayers for the first time. High Q-factors are also found in resonators based on MoS<sub>2</sub> and MoSe<sub>2</sub> monolayers. The high quality-factor found in this work opens new possibilities for coupling mechanical vibrational states to two-dimensional excitons, valley pseudospins, and single quantum emitters and for quantum opto-mechanical experiments based on the Casimir interaction. The sensing capabilities offered by these high Q-factor nanomechanical oscillators are also of interest for studying thermodynamic properties in condensed matter regimes that are difficult to access. In the second part of the thesis, we use optomechanical systems based on a MoSe<sub>2</sub> monolayer to probe the thermal properties of phonons in two-dimensional lattices. We measure the thermal conductivity and the specific heat capacity down to cryogenic temperature. The phonon transport crossover from the diffusive to the ballistic regime when lowering the temperature below ~100 K. The temperature dependence of the specific heat capacity approaches a quadratic dependence, the signature of two-dimensional lattices. Both the thermal conductivity and the specific heat capacity measurements are consistent with predictions based on first-principles. Our result establishes a new strategy to investigate thermal transport in two-dimensional materials, and allows for exploring the phonon hydrodynamic regime, the anomalous heat conduction, and the phase transitions of electronic many-body collective phenomena in monolayers.

**Monday December 17, 12:00 h. ICFO Auditorium**

**Thesis Advisor: Prof Dr Adrian Bachtold**