Dear Editor,

Please find our uploaded manuscript “Quantum theory of electron excitation and sputtering by transmission electron spectroscopy” that we are hereby submitting for consideration as an article in ACS Nano.

Electron beam irradiation by transmission electron microscopy (TEM) is an effective tool for defect engineering in 2-dimensional (2D) materials, potentially with atomic-scale precision. This degree of spatial control can provide powerful solutions to many of today’s most pressing challenges in nanotechnology, including quantum device fabrication, hydrogen evolution catalysis, and electronic device miniaturization. Often, beam-induced defects are initiated and sculpted through a process called sputtering, in which a beam electron knocks an atom out of the material. However, despite the broad application of TEM-driven defect engineering in materials science, current theoretical models fail to describe this effect, highlighting the fact that the non-equilibrium physics taking place during sputtering remains poorly understood. Specifically, existing models drastically underestimate sputtering rates in insulators, in which beam-induced electronic excitations may weaken the bonding between the irradiated atoms. Most notably, substantial sputtering is experimentally observed at beam energies deemed far too low to drive atomic dislocations by present-day theories. To address this anomalous behavior, this work develops the first quantum electrodynamics (QED)-based method to accurately describe electron beam-induced sputtering cross sections in 2D crystals by explicitly calculating the probabilities of beam-induced electronic excitations and their effects on sputtering kinetics. The consideration of excitations yields cross sections that quantitatively match experiment and correctly predict appreciable sputtering rates at beam energies previously predicted to leave the crystal intact. This new predictive theory can pave the way for the use of TEM for top-down atomic-scale defect engineering of 2D insulators.

We feel that this work meets the acceptance criteria of *ACS Nano*, as it significantly advances the state of the art in modelling the response of materials to electron irradiation. The QED-based prediction of excitation rates could also push efforts to simulate both TEM images and electron energy loss spectra towards a more analytical, quantum field theory-based direction. Furthermore, we believe that this article will appeal to the diverse readership of *PRX*. We have attempted to present our findings in a logical and pedagogical manner, including sufficient background information and motivation to make our work accessible to a broad audience. At the same time, the article also provides in-depth derivations and technical details for experts who wish to reproduce our results.

This manuscript has not been published and is not under consideration for publication elsewhere. We have no conflicts of interest to disclose.

Thank you for your consideration.

On behalf of all the authors,

Anthony Yoshimura, PhD

Lawrence Livermore National Laboratory

Livermore, CA 94550, USA