Project title:

Size dependent mechanical behavior of cracked micro- and nanobeams: nonclassical modeling and experimental validation

During the past decades, micro- and nanoelectromechanical systems (MEMS and NEMS) have been an inseparable part of our daily lives. The MEMS and NEMS play important roles in many different fields of science, technology and industry, e.g., communication, manufacturing, environmental monitoring, health care, energy and aerospace. Beams with micro- and nanoscale dimensions have vast applications, for example as primary components in sensors and actuators, which are the basic devices for the MEMS and NEMS. The mechanical sensors based on the micro- and nanobeams are compact and cost-effective, offering high sensitive and real-time detections.

The micro- and nanobeams must be reliable and functional over their lifetime. However, they may crack due to manufacturing defects or damage caused by in-service loads and environmental effects. Therefore, it is of great significance to gain a thorough knowledge of the mechanical response of cracked micro- and nanobeams for the development of MEMS and NEMS. In addition, such knowledge can be important for the condition monitoring and maintenance of the micro- and nanodevices by an early detection of the presence, size, and location of cracks, or for innovative designs by intentionally forming multiple cracks in such devices to manipulate their mechanical responses and achieve desired frequencies.

The general scientific goal of the project is to study the mechanical behavior of the cracked micro- and nanobeams under realistic assumptions, through an interrelated experimental, analytical, and numerical approach. Inspired by the applications to the MEMS and NEMS, the proposed fundamental research will be focused on the bending, transverse vibration, and buckling problems. The proposed project is of an interdisciplinary nature aimed at answering to the following questions: (i) what are the kinematic continuity conditions at the cracked cross-sections in the miniaturized beams? (ii) how does the presence of edge cracks affect the bending, transverse vibration, and buckling behavior of the micro- and nanobeams?

A nonlocal elasticity theory and a beam theory will be used to formulate nonlocal models through the variational approach for the size dependent bending, transverse vibration, and buckling of the miniaturized cracked beams. In order to leave little room for ambiguity in the analytical results, the formulated models will be validated using carefully designed experiments and MD simulations. The nonlocal parameters of the model will be calibrated experimentally by conducting bending tests on the miniaturized intact cantilevers made of a silicon monocrystal, which is the most common material currently used in the MEMS and NEMS commercial productions. Physics based kinematic continuity conditions at the cracked cross-sections will be determined by conducting a series of in situ SEM/AFM bending, transverse vibration, and buckling experiments of FIB fabricated micro- and nanocantilevers with edge cracks. In parallel, the MD simulations will be conducted to perform virtual experiments and confront the outcomes with the experimental observations and findings.