A Topology Description Function Based Approach for Optimal Design of Piezoelectric Mass Sensors

Zheqi Lin, Xuansheng Wang
School of Information Science & Technology, Sun Yat-sen University, Guangzhou, 510006, China
Research Institute of Sun Yat-sen University in Shenzhen, Shenzhen, 518057, China

Mass sensors have attracted interest as a sensing platform for biomolecular and chemical detection. A great amount of research has been dedicated to the development of high performance mass sensors suitable for measuring masses down to molecular or atomic levels. Mass sensing based on piezoelectric actuation is a powerful label-free technique that is receiving broad attention for many applications. In the detection, a piezoelectric mass sensor's resonance frequency shift is measured to quantify the small mass attached to the structural surface. Using this principle, a piezoelectric mass sensor was demonstrated for real-time in situ chemical or gas detection. Piezoelectric mass sensors have the advantages of using only electrical means for sensing avoiding the complex optical detection equipment in silicon-based sensors. Moreover, because it is highly piezoelectric, it can withstand damping in water and perform in situ biodetection and quantification in water, which is advantageous when compared to the commercially prevalent enzyme linked immuno sorbent assays which are less sensitive and require tedious labeling.

In view of their potential in biosensor development, it is important to examine how a piezoelectric mass sensor's design affects its mass detection performance. The mass sensing behavior can be explained by the performance parameters, such as the mass sensitivity, the limit of detection or the minimum detectable mass, and the quality factor. These parameters are of considerable importance when developing a high performance mass sensor. Many theoretical and experimental works are available on modeling and applications of piezoelectric mass sensor. In the work reported, the effect of geometric parameters (length, width, and thickness) and material parameters (density and Young’s modulus), or electrical properties (capacitance and dielectric permittivity) on the performance of the piezoelectric mass sensor is examined. From the result, we confirm that the structures can be configured in different ways to improve the performance of piezoelectric mass sensors.

Topology optimization is a powerful design technique that has been successfully applied to stiffness maximization problems, eigenfrequency problems, compliant mechanism design, piezoelectric transducer design and so on. In this paper, a new approach for the design of piezoelectric mass sensors based on implicit topology description functions is proposed. The topology description function is used to describe the shape/topology of the structure, which is approximated in terms of its nodal values by finite element. The design goal is to obtain the configuration of material that maximizes the mass sensitivity of the senor. In the view of mass sensor development, the mass sensitivity is an important characteristic representing the sensor performance. A definition of mass sensitivity is the resonance frequency shift as a function of added mass on the sensing area. Numerical examples are presented to demonstrate the validity of the proposed problem formulation.