Piezoresistive Cantilever Array for Chemical and Biological Detection

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Detection and characterization chemical and biological analytes in real-time with miniature sensors with extreme high sensitivity has immediate relevance in many areas. Determination of location, chemical composition, and level of suspected analytes with exceptional sensitivity and extreme high selectivity is essential. Current sensing technologies fail to show the potential for broad deployment due to intrinsic limitations in volume, weight, power, and expense. However, microcantilever sensor arrays offer a clear path to the development of miniature sensors with very low power consumption. Microcantilever sensors have unmatched detection sensitivity compared to any other sensor platform. When molecular adsorption is confined to a single broad surface (by applying a suitable coating), the cantilever undergoes bending due to changes in surface stress (surface free energy). Due to the large surface-to-volume ratio for these micron-size levers, the bending signal is extremely sensitive. Selectivity is attained by applying chemically selective coatings on cantilevers in an array, similar to Surface Acoustic Wave (SAW) sensors. However, unlike SAW sensors, hundreds of microcantilevers can be packaged into a small sensor.

The piezoresistive method of cantilever signal transduction is ideal for miniature sensors. This method is extremely sensitive and can be used for vapor as well as liquid applications. Conventional piezoresistive cantilevers are fabricated by changing the doping level of silicon cantilevers along the thickness of the cantilever by ion implantation; cantilevers fabricated by ion implantation often show uncontrolled drift, poor signal to noise ratio, and unpredictable electrical properties. Piezoresistive cantilevers fabricated without ion implantation show excellent properties. These cantilevers are fabricated using pre-doped silicon with insulating layers of silicon nitride on both sides. The thickness of the silicon nitride layers is adjusted in such a way as that neutral axis of cantilever bending is not inside the doped silicon. Cantilevers fabricated using this technique show improved signal to noise ratio, reduced cantilever drift, and greater sensitivity. Silicon nitride is an insulating layer so these piezoresistive cantilevers can be used in liquid environments. Therefore, piezoresistive cantilever arrays offer an ideal platform for miniature sensors for chemical and biological detection.

Although microcantilevers have high sensitivity, they do not offer any intrinsic selectivity. We have developed a number of techniques by which chemical selectivity can be accomplished without increasing the overall dimensions of the integrated sensor system. Silicon cantilevers with a thin layer of gold are used to detect a few targeted analytes with high selectivity. Modifying the gold surfaces with a self-assembled monolayer of specifically designed probe molecules allows extremely high selectivity for targeted analytes. In most cases selectivity is achieved using coatings such as polymers, biomolecules, and self-assembled monolayers. We have also developed a technique for functionalizing the individual elements in a cantilever array with the selected molecular recognition layer.

We have demonstrated the detection of a number of chemicals and biomolecules using a piezoresistive cantilever array. The sensitivity obtained using these piezoresistive cantilevers is comparable to that of results obtained using the optical beam deflection method. In vapor phase detection we have demonstrated sensitivity in the range of parts-per-trillion for explosive vapors. Recent results ranging from explosive vapors to protein and DNA detection will be presented.