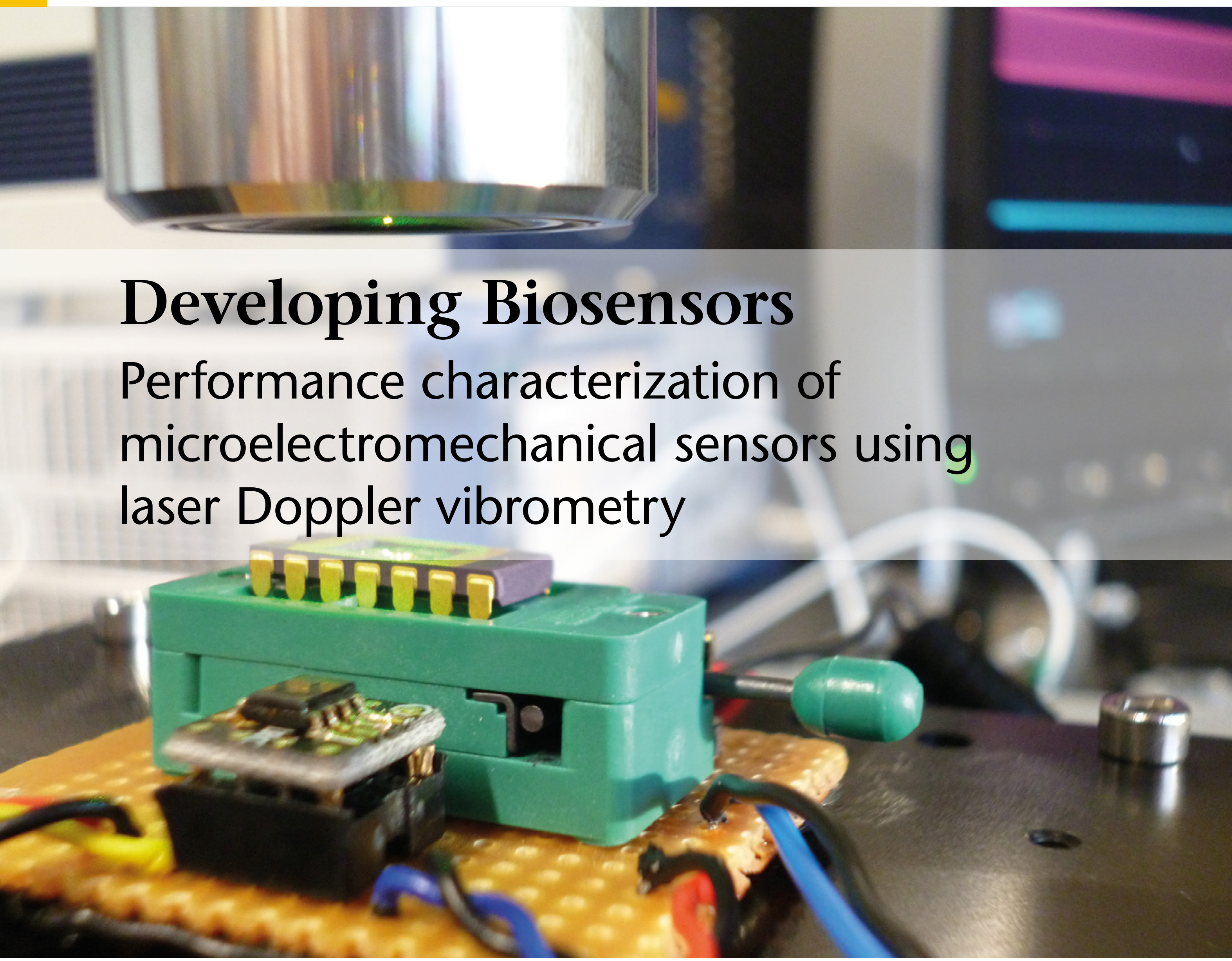
Polytec



Developing Biosensors

Performance characterization of microelectromechanical sensors using laser Doppler vibrometry

The ability to characterize the motion of micro devices at high frequency with sub-nanometer resolution is key to the development of next generation resonant-based sensor technology. ►

Micro fabrication processes herald a new generation of healthcare technology where point-of-care sensors promise increased sensitivity at low cost, and readout times within minutes.

The highest sensitivity is gained from high quality factor resonating devices in which the addition of mass onto the sensor causes a shift in the resonant frequency of the device.
A novel sensing approach being developed at Newcastle University utilizes degenerate modes of vibration. For a given sensor geometry, a pair of degenerate resonant modes are chosen. In a perfectly fabricated device, symmetry in the system dictates that the frequencies of both modes are identical (Figure 1). With functionalization of the sensor, biomolecules can be immobilized to specific regions of the sensor surface, namely the antinodal position of one of the modes, thereby breaking this symmetry and introducing a split in frequencies between the modes. This split is proportional to the mass added to the sensor but insensitive to non specific binding events and temperature fluctuations (Figure 2), making for a robust technology.

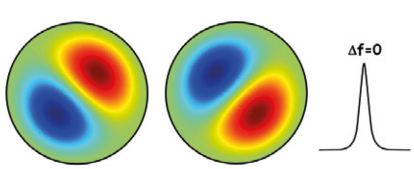


Figure 1: The mode shapes for the (1,0) vibration of a circular diaphragm. For a symmetric device, the modes form a degenerate pair.

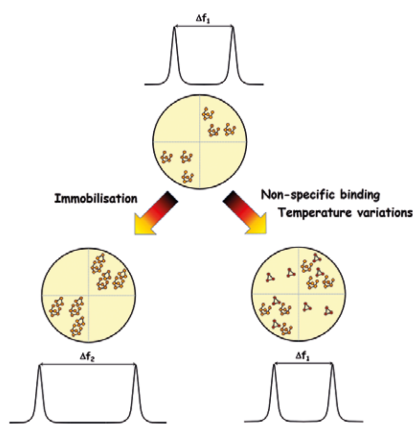


Figure 2: Upon functionalization of the sensor, degeneracy is broken and the modal frequencies show a split of Δf_1. Addition of mass to the antinodal position of the functionalized mode increase this split to Δf_2. For non specific variations, the split remains unaltered.

DEVICE DESIGN AND FABRICATION

Previous incarnations of the sensor design utilized a 4.5 µm thick crystalline silicon diaphragm, capacitively actuated and sensed through electrodes contained within a sealed cavity beneath the device. The drawback of this approach was complex signal recovery electronics which ultimately raises the price of what would be a disposable sensor. The latest design iteration, funded through EPSRC (EP/G061394/1), incorporates a 750 nm thick piezoelectric (PZT) film deposited onto the silicon diaphragm. A 200 nm silicon oxide layer provides a means to define electrode regions and then by application of voltage across an electrode, the resulting induced bending moment drives the device into motion.

Manufacture of the device utilizes cleanroom fabrication processes. The design must account for fabrication tolerances of ±2 µm. Two silicon wafers, one of which is patterned, are bonded together to form a circular diaphragm resonator. A platinum base electrode is used as the foundation layer for the subsequently spun-on PZT thin film with patterned oxide and gold layers forming the top electrodes and immobilization regions (Figure 3). The wafers are then diced and individual devices (Figure 4) packaged.

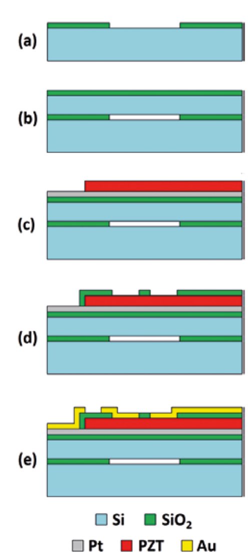


Figure 3: The process flow for fabrication of the sensor.

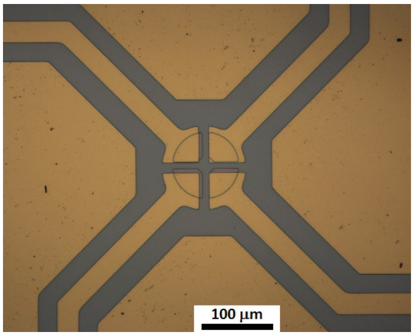


Figure 4: Microscope image of a fabricated sensor.

SENSOR CHARACTERIZATION

Ultimately, device motion is sensed utilizing on-board electronics, however prior to development of this electronic solution, sensor performance is characterized using laser Doppler vibrometry.

Devices are characterized under vacuum, at atmospheric pressure and within a liquid. Key measurements are resonant frequencies and quality factors of the modes. Results indicate that due to the high electromechanical coupling factor of the PZT, performance between vacuum and atmospheric conditions are comparable however due to the mass loading of a liquid environment, the reduction in performance renders an electronic solution for this scenario to be problematic.

Mode shape alignment is a key issue to sensitivity. As the designed geometry dictates where molecules will be immobilized onto the sensor surface, it is important that this position corresponds to the antinodal position of the required mode. Fabrication inaccuracies lead to modal misalignment, so an accurate mapping of each mode shape is required at this stage of development. For a given modal alignment, mass sensitivity is assessed by electroplating additional gold onto the sensor surface.

RESULTS AND FUTURE WORK

Preliminary results indicate a device mass sensitivity of 12.0 Hz pg^{-1} (full details may be found in J. Micromech. Microeng. 23 (2013) 125019). Work is in progress to develop frequency tracking electronics for the measurement of biomolecule immobilization onto the sensor surface.

The preliminary investigation of the sensor was performed with a fiber-optic vibrometer from Polytec giving characterization up to 20 MHz. Through recent equipment funding from EPSRC, a UHF-120 system now extends the group's characterization facilities up to 1.2 GHz. With device sensitivity scaling with operational frequency, this vibrometer upgrade allows analysis of higher order modes of the current sensor design and development of ultra high frequency surface acoustic wave sensors (SAWs). This UHF vibrometer also acts as an external user facility and we therefore look to assist other research groups and institutes in characterization of their high frequency devices. ■

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