To my parents

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ABSTRACT

This work explores the use of bulk micromachined piezoelectric transducers for ultrasonic heat generation. The work includes basic studies of the phenomenon, the development of simulation models, the design and fabrication of practical devices and interface circuits. The technology is demonstrated in two application contexts: cauterization with a biopsy needle, and stimulation of insect locomotion.

Simulations based on three-dimensional finite element models, indicate that circular disc-shaped elements provide superior steady-state temperature rise for a given cross-sectional area, volume of the PZT element, and drive voltage. The heating is greatest at the frequency of maximum electromechanical conductance. The thermal efficiency is maximized at frequency of maximum electromechanical impedance. Stacked PZT heaters provide 3.5x the temperature rise and 3x greater efficiency than single elements.

A biopsy needle with an embedded array of four piezoceramic microheaters of 200μm diameter and 70-80μm thickness has been fabricated. The PZT-5A heaters generate the target temperature rise of 33°C at the tissue-needle interface for an input power of <325 mW and a drive voltage of <17V_{RMS} when inserted into porcine tissue. The extent of tissue cauterization is <1.25mm beyond the perimeter of the needle. Cauterization of porcine tissue sample results in a decrease of 600kHz in the resonance frequency and 900ohms in the peak impedance magnitude, allowing the extent of cauterization to be monitored easily. Interface circuits for measurement of resonance frequency shift due to cauterization and for actuation of PZT heaters are also described.

Experiments have been conducted using piezothermal stimulators implanted near antennae of green June beetles (GJB), and on either side of the thorax of Madagascar hissing roaches and green diving beetles (GDB) to show the feasibility of locomotion control using microthermal stimulation. Thermal stimulation causes the insects to move away from the direction of the actuated stimulator. Thermal stimulation achieves an overall success rate of 80%, 93.5% and 68% in GJB, roaches and GDB, respectively. On average, thermal stimulation results in an angle turn of about 15°-18° on GJB, 30°-45° on the roaches and 15°-60° on GDB. The corresponding average input power is 360mW, 330mW and 100mW for GJB, roach, and GDB, respectively.