Abstract:
Three-dimensional mapping of physioelectrical activities in in vitro cardiac tissues is highly desirable for the study of mechanism and development of cardiac arrhythmias. Important information can be obtained for prediction and prevention of arrhythmias, especially ventricular arrhythmia—one of the leading causes of mortality in the United States. In this paper, we present ultrasonically actuated silicon microprobes to reduce insertion force and minimize tissue damage. Probe tips with multiple recording sites were successfully inserted into canine heart tissue and cardiac signals in two dimensions were recorded. To our knowledge, this is the first ever in vitro cardiac signal recordings by micromachined silicon electrode array at this scale.

Silicon-based microprobes have been reported for electrical activity recording in neural tissues (Wise, 1970). They provide high spatial resolution, reduced tissue damage, and ease to integrate with microelectronics. However, these thin probes do not have enough rigidity to go in the much denser and harder cardiac tissues, and easily buckle and break. Thicker probes provide greater rigidity but the increased probe size causes more damage to the tissue being investigated and may affect their physioelectrical activities. Integrating an ultrasonic actuator with the silicon microprobe preserves all the advantages of microprobes while reducing the force required to penetrate and cut cardiac tissues, enabling use of thinner and less invasive microprobes.

Fabrication:
The device consisted of a silicon ultrasonic horn actuator [Lal, 1996] with a longitudinal l/2 resonance at 75kHz. Two thin beam tips were defined at the small end of the horn to be driven longitudinally. The thickness of the tips (ranging from 70 µm to 140 µm) was defined by DRIE on front side and the probe is released by wet etching from the back side. The tip length varies from 5 mm to 1 cm for penetration of heart walls of different thickness. A dummy probe without a tip was bonded to the probe for symmetry and reducing bending mode of the tips. PZT4 plates were bonded to the device for ultrasonic driving. The device is clamped to a customized PC board at resonance node. The PC board also provides metal pads for electrical connection from the Pt/Cr electrodes on the probe through wire bonding. A ground layer was also patterned on top of the conduction paths to reduce cross-talking between channels.

Results:
Penetration and cutting force measurements show that both forces reduced as ultrasonic driving voltage increased. Cardiac signal recording was conducted on isolated and perfused canine heart. The probes successfully penetrated the tissue at 6~10 Vpp driving voltage, and both spontaneous fibrillation and externally stimulated rhythmic signals were recorded with qualities comparable to those obtained by conventional metal wire probes. Signals from different recording sites were compared and phase/morphology differences can be used for later reconstruction of physioelectrical wave propagation in the heart. Furthermore, signals recorded with/without the presence of ultrasound showed little difference other than some easily filtered high frequency noise, indicating the low voltage ultrasonic driving posed no significant modification on heart cells’ electrical activities.

References:
Figure 1: Assembled device.

Figure 2: Penetration force decreases with increasing ultrasonic driving on canine left ventricle.

Figure 3: Time delay between channels indicating a conduction speed of 0.6m/s in canine right ventricular wall.

Figure 4: Electrical activity recorded showing a development of ventricular fibrillation.