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HiFFUTs for High Temperature Ultrasound

Andrew Feeney, Lei Kang, and Steve Dixon
Centre for Industrial Ultrasonics, Department of Physics, University of Warwick, Coventry UK
a.feeney@warwick.ac.uk

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1. The High Frequency Flexural Ultrasonic Transducer – the HiFFUT

The HiFFUT, shown in Figure 1, is a high frequency flexural ultrasonic transducer. It operates through a piezoelectric ceramic bonded to a metal cap, in this case grade 2 titanium. The membrane constrains the ceramic, whose vibration motion causes it to bend, generating an ultrasound signal.

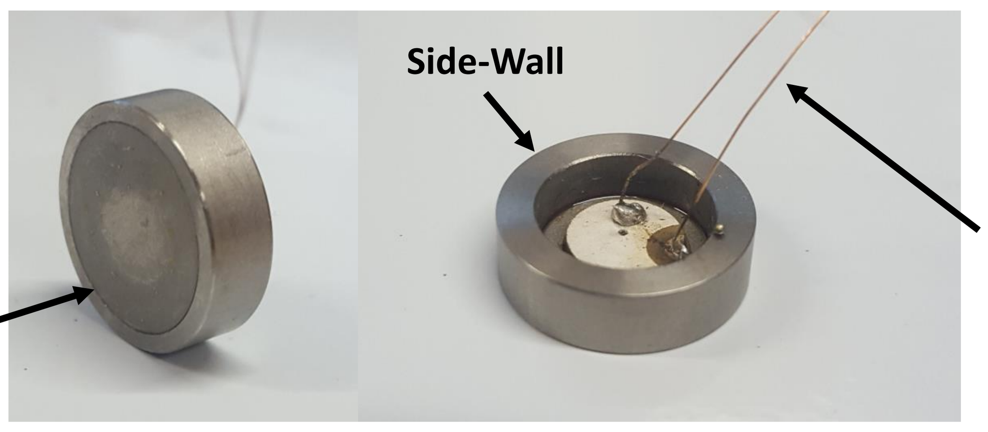

Figure 1: A high-temperature HiFFUT.

HiFFUT efficiency depends on the bending of the membrane, and the transducer does not require matching layers for low impedance media. HiFFUTs are intended for operation in applications of high frequency (over 50 kHz, up to 1 MHz), pressure (around 300 bar), and temperature (up to approximately 500°C), including industrial flow meters, oil production, and NDE in hostile environments. Axisymmetric modes are shown in Figure 2.

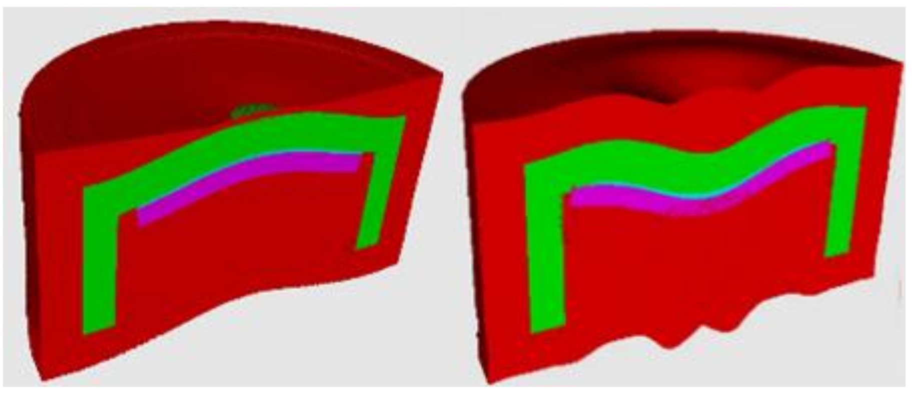

Figure 2: PZFlex® simulated mode shapes of a HiFFUT, showing (a) the (0,0) mode, and (b) the (1,0) mode.

2. HiFFUT Fabrication Process

The fabrication process for the titanium HiFFUTs is illustrated in Figure 3.

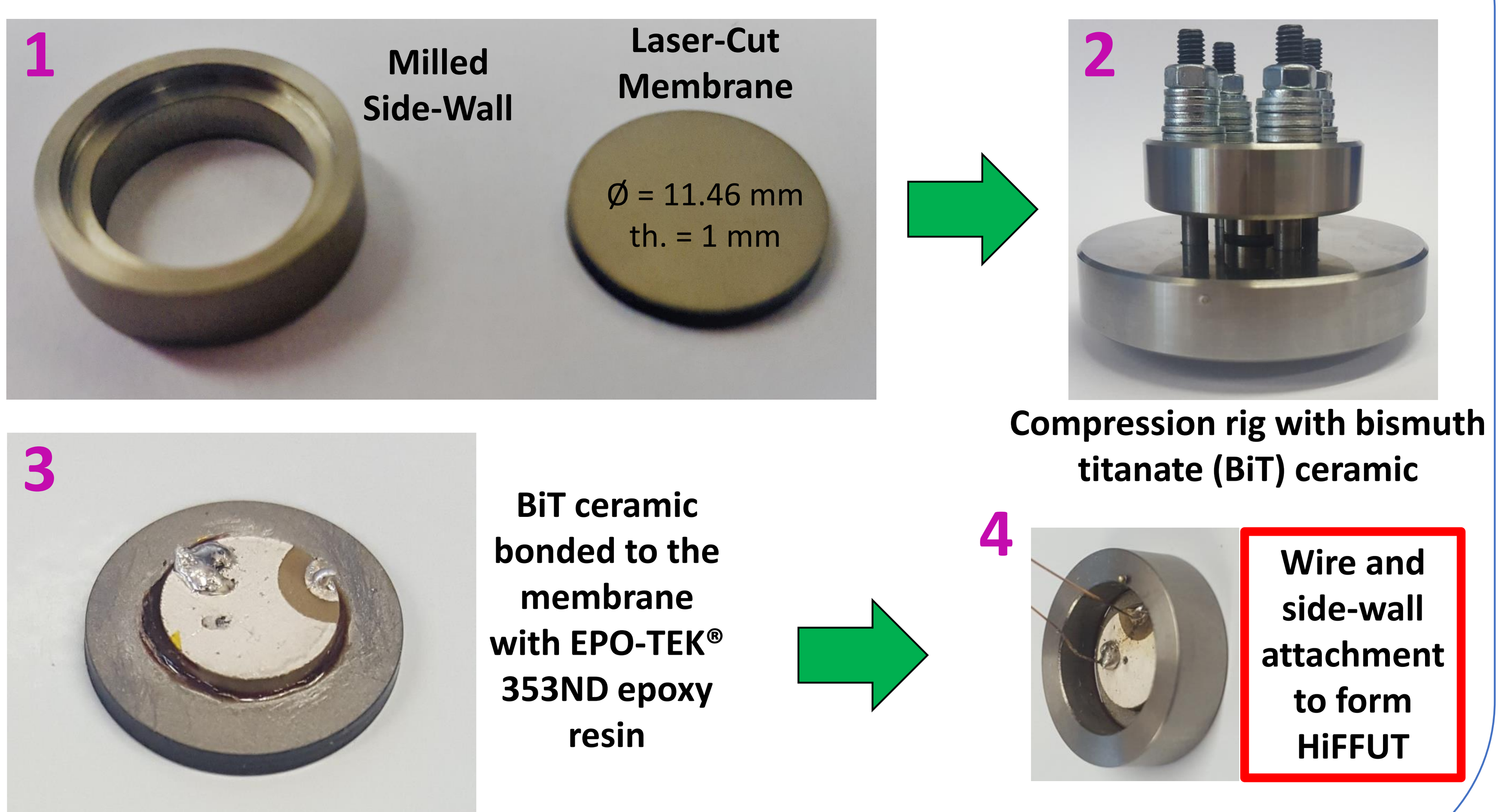

Figure 3: The HiFFUT fabrication process.

3. Experimental Method

Two HiFFUTs are studied. The experimental process is shown in Figure 4, where an acoustic microphone and laser Doppler vibrometer are employed to characterise the HiFFUT modes, and an acoustic microphone is used to measure the dynamic performance of the HiFFUTs heated in a furnace.

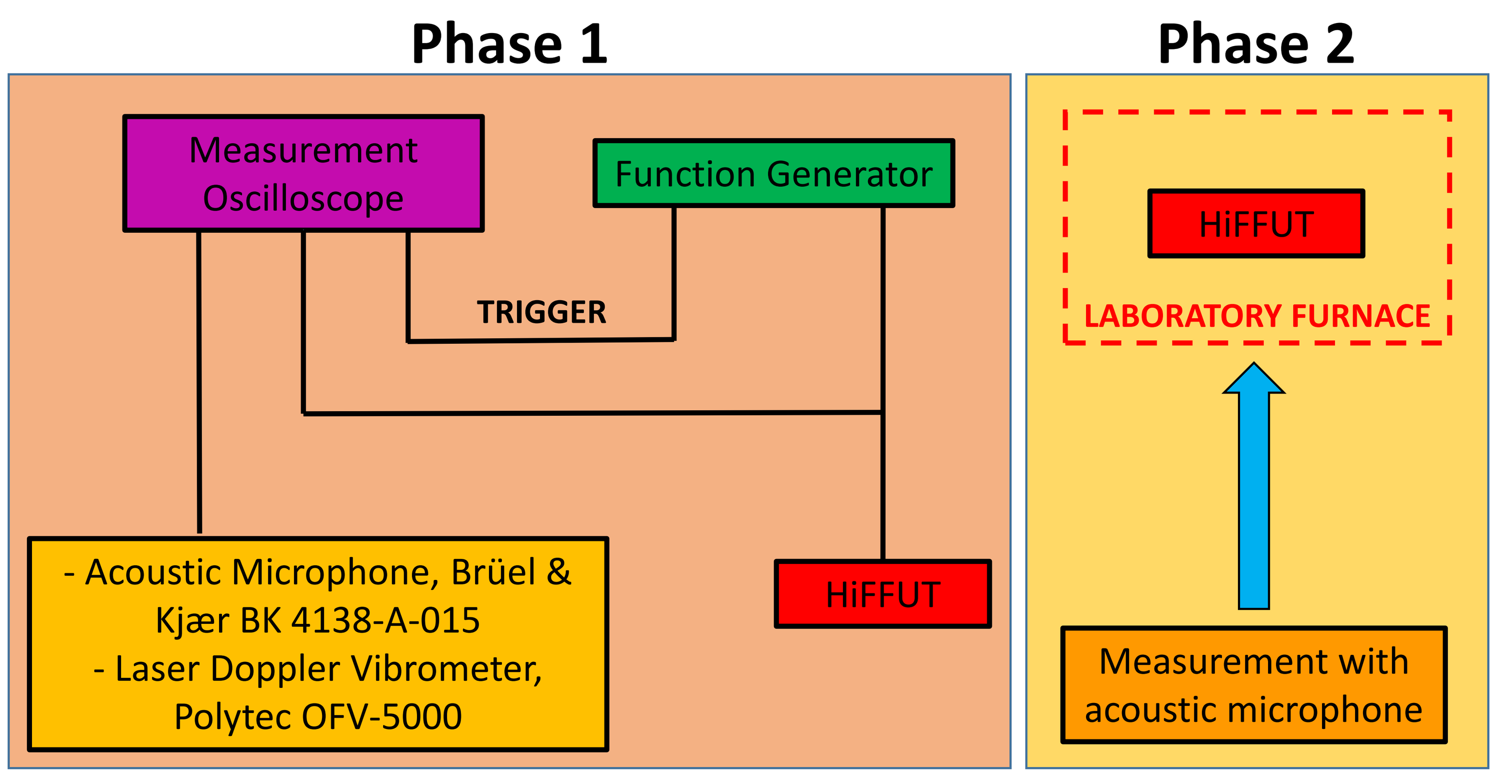

Figure 4: Experimental process schematic for the characterisation of HiFFUTs.

4. Resonance Measurement

The mode shape of HiFFUT 1 from laser Doppler vibrometry (LDV), shown as an example, and the amplitude-time spectra for both HiFFUTs from the microphone prior to temperature measurement, are exhibited in Figure 5. The results show resonance of both HiFFUTs at high frequency, above 50 kHz.

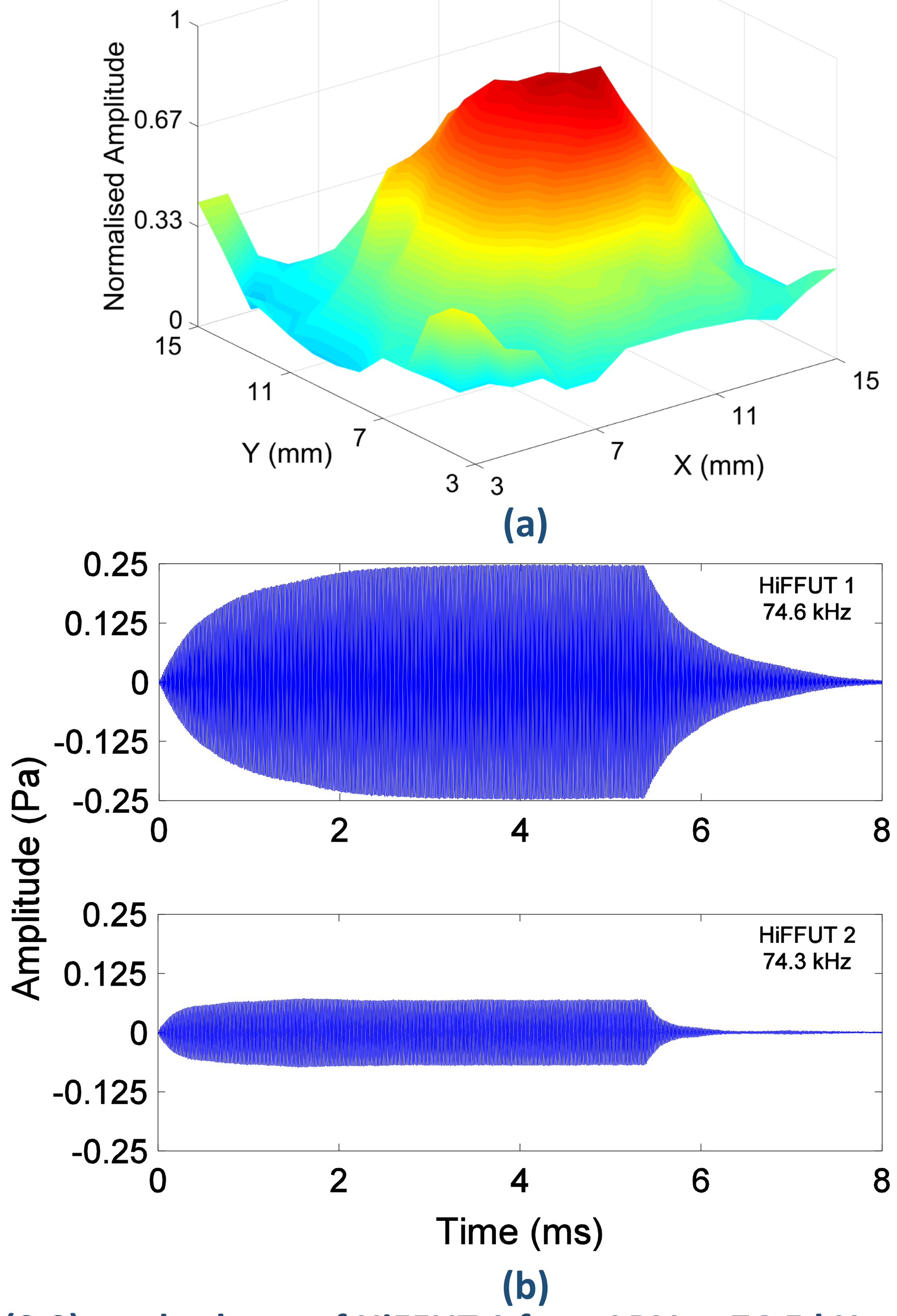

Figure 5: (a) The (0,0) mode shape of HiFFUT 1 from LDV at 74.5 kHz, and (b) the amplitude-time spectra for each HiFFUT, showing HiFFUT 1 at 74.6 kHz, and HiFFUT 2 at 74.3 kHz.

The resonance frequencies of the HiFFUTs differ, likely as a consequence of discrepancies in fabrication. There is also a minor difference between the resonance frequencies of HIFFUT 1 from LDV and the microphone, postulated to be due to differing clamping used for the two methods.

5. Thermal-Vibration Characterisation

Amplitude-time spectra were recorded at ambient room temperature, 50°C, 100°C and 150°C. HiFFUT functionality post-150°C thermal testing is shown in Figure 6(a), and centre frequency drift of HiFFUT 2 is exhibited in Figure 6(b), computed by using the fast Fourier transform (FFT).

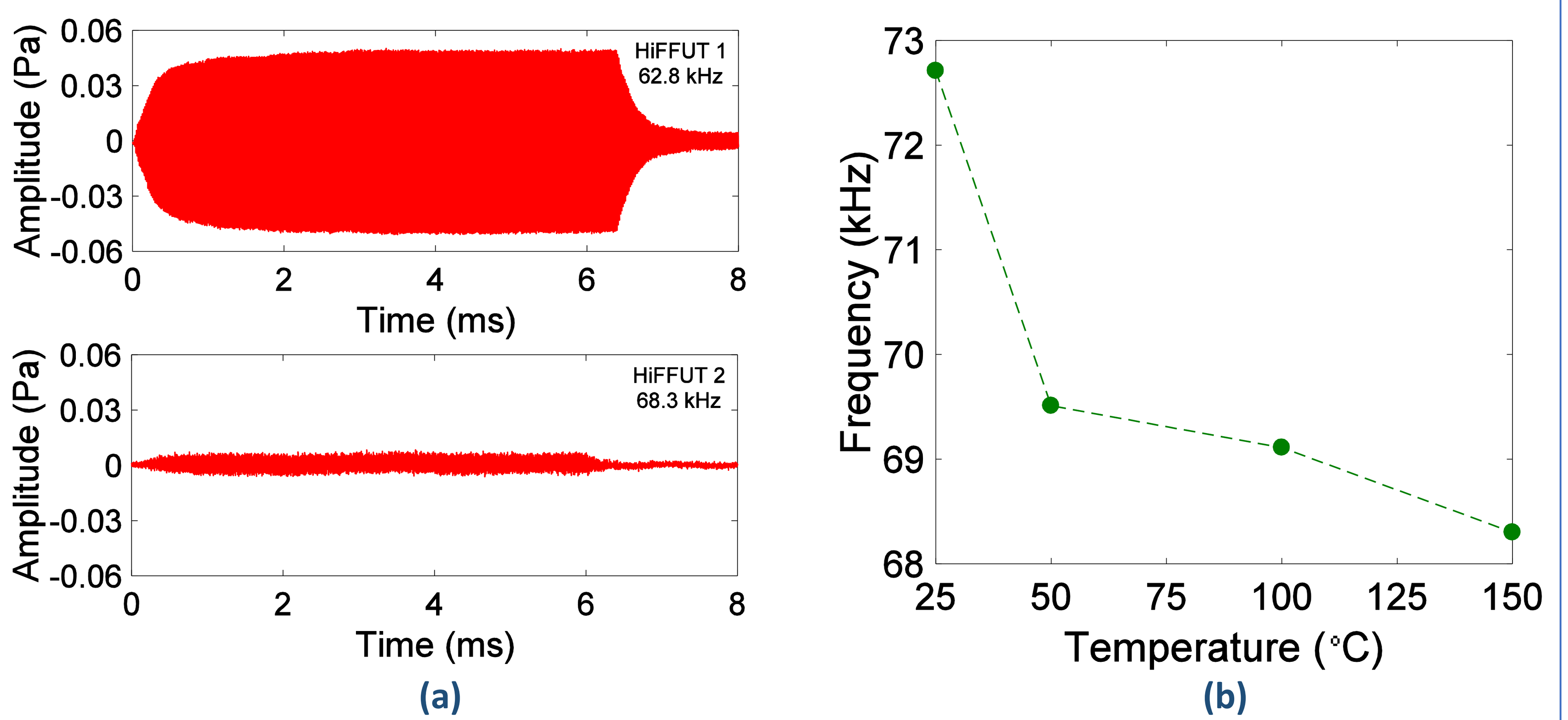

Figure 6: (a) The amplitude-time spectra for each HiFFUT measured post-thermal testing, and (b) dynamic performance as a function of temperature for HIFFUT 2.

As each HiFFUT is heated, it undergoes thermal expansion of its different components, thus affecting the centre frequency and its dynamics. Despite the functionality of the HiFFUTs at high temperature, their dynamic performances are limited through thermally-induced frequency drift.

6. Summary and Future Research

The design, fabrication, and characterisation of two HiFFUTs for high temperature applications has been demonstrated. The HiFFUTs are able to generate ultrasound at the desired frequency level, over a relatively wide temperature range, making the device a feasible candidate for industrial applications. However, the HiFFUTs exhibit decreases in centre frequency with temperature and relatively low efficiency, and so improvements are necessary for future application.

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