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In-Vitro Ultrasound Evaluation of an Acoustic Metamaterial Sensor in Presence of Tissue Mimicking Material

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Summary:

Acoustic metamaterials can be exploited to develop new concepts for passive, implantable sensors interrogated by ultrasound. Tissue introduces scattering and attenuation, which may affect the performance of such sensing devices. In this work, we assess the temperature sensitivity of a passive acoustic metamaterial in presence of tissue mimicking materials (TMMs), which are artificial materials with similar acoustic properties to real tissues. We demonstrate that the sensor is still detectable by ultrasound and the presence of TMMs does not affect the temperature sensitivity of the sensor.

Keywords: acoustic metamaterial, implantable device, temperature sensor, tissue mimicking materials, ultrasounds

Introduction

Ultrasound acoustic metamaterials open the way to new passive sensing concepts for implantable sensors. Acoustic metamaterials are artificial materials which enable the selective and engineered control of acoustic wave propagation.

In our previous work, we demonstrated how this concept can be applied to passive temperature sensing, reaching unprecedent resolution (30 mK) and sensitivity ($2.9 \cdot 10^{-3}$ K^{-1}) [1] (see also Fig. 1). There, we speculated that the operation principle, based on reading the frequency of an acoustic resonance, is less susceptible to noise and attenuation than amplitude-based read-out schemes. Implantable applications will have to cope with the presence of biological tissue which creates scattering and introduces attenuation [2].

In this work, we analyze the temperature response of the sensor in the presence of tissue mimicking materials (TMMs). TMMs are artificial materials having similar acoustic properties to in-vivo tissues such as attenuation, density, and speed of sound.

Methods

An ultrasonic probe centered at 5 MHz (Technisonic ISL-0502-HR), connected to a pulser-receiver (Olympus 5072PR), is used to interrogate the metamaterial.

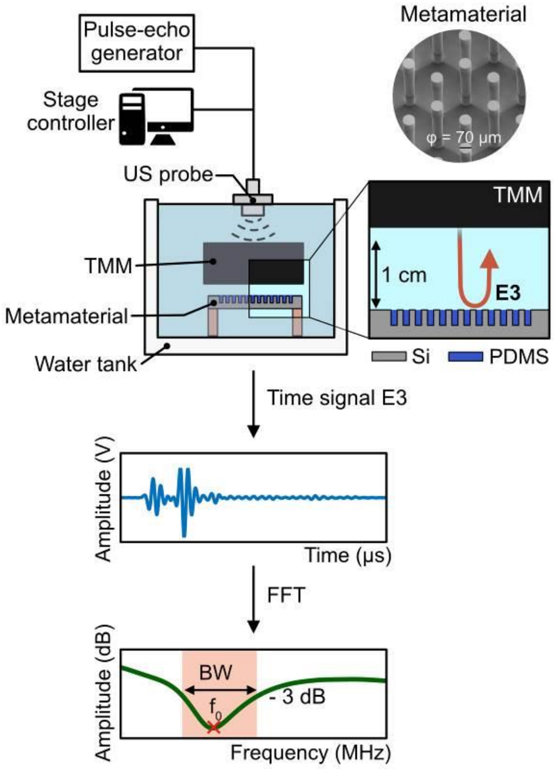

Fig. 1. Experimental setup used in this work and details of the metamaterial. The reflected signal at the interface between the TMM and the metamaterial (E3) is recorded in time and transformed in the frequency domain (FFT). An algorithm was implemented to compute the frequency peak (f_0) and the bandwidth (BW) at -3dB from f_0.

The probe is connected to an x-y-z stage controller to perform spatial scanning.

The metamaterial is produced with silicon (Si) micromachining and poly-dimethyl-siloxane (PDMS) casting, according to the process flow described in [1]. The TMM is produced from a mix of 2 % agar and 8.2 % graphite powder in water, reoptimized from [3] to match the attenuation coefficient of real muscle tissue.

The metamaterial and the TMM are immersed in water. The signal (E3) is recorded at the interface of the metamaterial (Fig. 1). A Fourier transform is applied (FFT) and an algorithm is implemented to find the frequency peak f_0 and the -3dB bandwidth (BW) around it.

Results

The resonant frequency signals of the metamaterial, with and without TMM, show a shift of the frequency peak at different temperatures (Fig. 2). The temperature sensitivity is almost identical with and without TMM ($S = -3.6\cdot10^{-3}\ K^{-1}$). The presence of TMM seems not to affect the position of the resonant frequencies at the different temperatures either (see dotted lines, Fig. 2 and also Tab. 1). The bandwidth BW is on the other hand side affected by the TMM. The resonances become broader due to the attenuation introduced by the TMM. The impact on temperature resolution will be studied in more detail in the future.

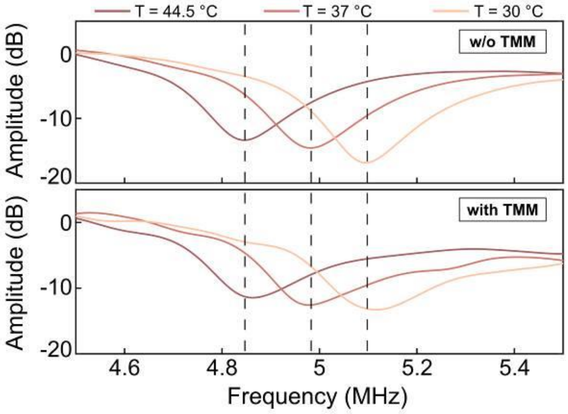

Fig. 2. Reflected frequency signal E3 in the frequency-domain (after FFT) of the metamaterial without (top) and with (bottom) TMM, recorded at three different temperatures. Dotted lines showing the positions of f_0.

Spatial scans shown in Fig. 3 demonstrate that the presence of the TMM does not hinder the full detection of the metamaterial (see Fig. 3-B).

Because the sensing mechanism is based mostly on the position of the resonance frequency, the attenuation introduced by the TMM seems to be a second order effect, as supported by the unchanged temperature sensitivity.

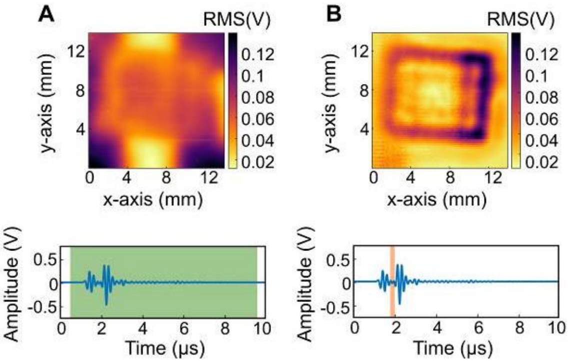

Fig. 3. Ultrasonic spatial scan at T = 44.5 ˚C of the metamaterial with TMM. In (A): the root-mean-square voltage of the entire signal is displayed (green band), vs. a windowed part in (B) (orange band). In (B), the outline of the sensor is clearly visible.

A summary of the extracted resonance frequencies and bandwidths at different experimental temperatures is reported in Table 1.

Tab. 1: Experimentally measured figure of merits (f_0: resonance frequency and bandwidth: BW) at different temperatures, with and without TMM (tissue mimicking material)

Temperature

	44.5˚C		37˚C		30˚C	
	f_0 (MHz)	**BW (kHz)**	**f_0 (MHz)**	**BW (kHz)**	**f_0 (MHz)**	**BW (kHz)**
w/o TMM	4.84	135	4.98	139	5.1	118
TMM	4.86	173	4.98	189	5.12	190

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