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Low voltage acoustic particle velocity sensor with integrated low noise chopper pre-amplifier

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Abstract

Novel acoustic particle velocity (APV) sensors suitable for low voltage, battery-powered systems are proposed. The sensing structure consists of four silicide polysilicon wires placed over suspended dielectric membranes and arranged in a Wheatstone full-bridge configuration. The device has been fabricated combining a commercial CMOS process with a simple and low cost post-processing technique. An ultra low noise chopper pre-amplifier has been integrated on the same chip. Preliminary noise and acoustic characterization is presented.

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Keywords: Acoustic sensors; Chopper amplifier; Microsensors; Micro-electro-mechanical systems (MEMS).

1. Introduction

Silicon microsensors for detecting acoustic particle velocity (APV), consisting of thin platinum wires placed over parallel suspended silicon nitride bridges, were firstly proposed by de Bree et al. [1,2]. The device has been developed increasing sensitivity [3] and including multi-dimensional probes on a single chip [4], and a few commercial products are available [5]. These sensors, usually combined with traditional microphones, have been proposed for different applications including acoustical source finding and noise cancellation. Nevertheless long parallel suspended wires are intrinsically fragile and APV sensors based on more mechanically robust crossed-wire configurations have been proposed [6]. Furthermore, a dedicated technology process, not compatible with those used

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for the integrated circuit fabrication, is used to make the APV sensors proposed in [1-6]. This precludes the possibility of integrating on the same chip both the sensing structure and the read-out electronics and determines high production costs limiting the diffusion of these sensors to niche markets.

Recently, we have demonstrated the possibility of fabricating APV sensors, consisting of two 800 Ω wires arranged in a half-bridge configuration, by means of an inexpensive CMOS compatible process [7]. These sensors have been used for fabricating devices with a programmable directivity [8] and compact probes for acoustic impedance measurements [9]. Nevertheless, the low sensitivity of the proposed solution enforced the use of high supply voltages (12 V-40 V), not compatible with modern analog integrated circuit requirements.

In this work we proposed a novel device suitable for low voltage applications. Since the sensitivity is proportional to the dc voltage, we have partially recovered the detection limit degradation caused by low supply voltage by doubling the sensitivity with a full-bridge configuration and lowering the wire resistance (100 Ω) in order to reduce thermal noise. Furthermore, differently from [7], a low noise chopper pre-amplifier has been integrated on the same chip.

2. Device design and fabrication

The chip has been designed with the BCD6s process of STMicroelectronics and simple post-processing steps were applied to thermally insulate the sensing structures from the substrate. Optical micrograph in Fig. 1 shows the chip area including the pre-amplifier and the sensing structure at the end of the fabrication process.

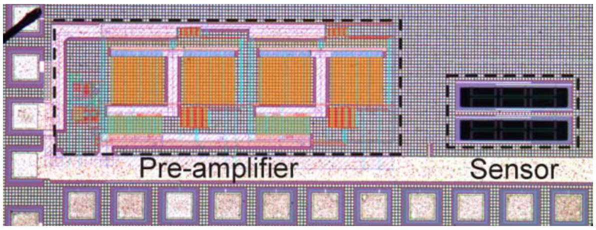

Fig. 1. Optical micrograph of the chip area including the sensing structure (right) and the pre-amplifier (left); the pre-amplifier layout has been superimposed on the area covered by planarization dummies for clarity.

2.1. Sensing structure

The sensing structure is made up of four silicide polysilicon wires arranged in a Wheatstone full-bridge configuration. In order to increase the mechanical robustness of the structure maintaining, at the same time, a low resistance value, each wire has been divided into three sections electrically connected in parallel and each section has been placed over a U-shaped dielectric membrane.

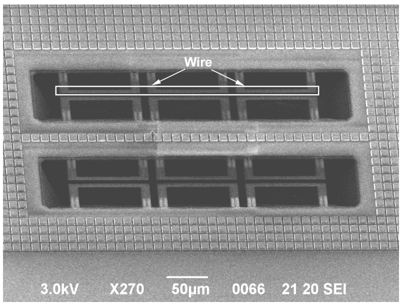

Fig. 2. SEM micrograph showing the suspended membranes after the silicon etching with a TMAH solution; each wire consists of three sections electrically connected in parallel.

In Fig. 2 a SEM micrograph of the sensing structure after post-processing is shown: the three 300 Ω resistors, connected in parallel to form one of the four 100 Ω wires of the bridge, are indicated.

The post-processing phase is similar to that described in [10]. Briefly, dielectric layers in the front side of the chip were selectively removed with reactive ion etching (RIE) in CF4 / Ar (50% / 50%) gas mixture using thick photoresist as mask. Then, the silicon substrate has been anisotropically etched in a solution of 100 g of 5 wt% TMAH with 2.5 g of silicic acid and 0.8 g of ammonium persulfate.

2.2. Pre-amplifier

The schematic diagram of the pre-amplifier connected to the sensor bridge ($W_{1,4}$) is shown in Fig 3. The integrated pre-amplifier is formed by a simple resistor-loaded MOSFET differential pair ($M_{1,2}$) and two switch arrays (SA_1-SA_2) implementing chopper modulation, necessary for reducing the typically high flicker noise density of CMOS devices. Resistance R_B is used to set the bridge supply voltage (V_{bridge}) while C_{LP} are used to reduce the chopper ripple; C_{HP} and R_{HP} form a high pass filter to reject output dc components. The nominal gain was set to a value (around 28) sufficient for making the noise contribution of subsequent amplification stages (off-chip) negligible. Use of an integrated preamplifier strongly improves immunity to electromagnetic interference, a problem that is particularly serious due to the extremely low level of the sensor output signal.

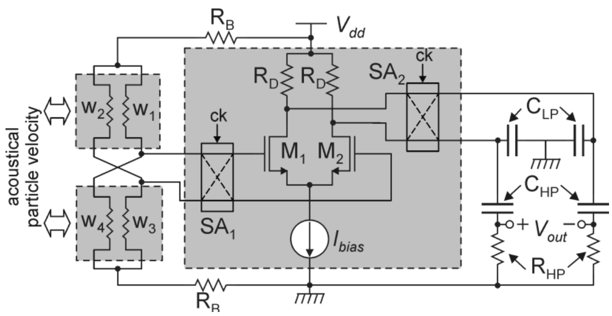

Fig. 3. Schematic view of the device: the components in the grey boxes (chopper pre-amplifier and wires $W_{1\text{-}4}$) are integrated on the chip.

3. Device Characterization

A first series of tests has been dedicated to measure the noise performances of the integrated pre-amplifier. Fig. 4 shows the input referred noise of the pre-amplifier compared to the noise measured when the pre-amplifier is connected to the bridge with V_{bridge}=2.2V. It can be noted that the noise introduced by the pre-amplifier is negligible with respect the bridge noise.

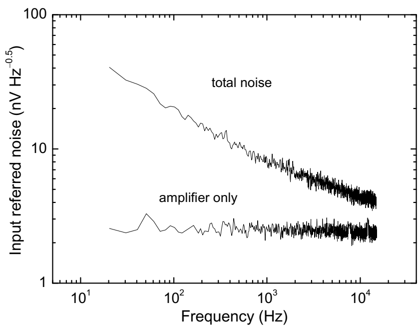

Fig. 4. Input referred noise spectral density in the band 20 Hz – 10 kHz. The amplifier noise has been measured with input terminals shorted.

Acoustic response has been characterized with the standing wave tube technique [7]. Fig. 5 shows the device sensitivity and wire overheating as a function of the bridge voltage. A linear behavior can be observed for bridge voltage greater than 0.8 V. Considering the total noise in the 20 Hz-10 kHz band, the sensor detection limit at V_{bridge}=2.2V is nearly 80 dBa.

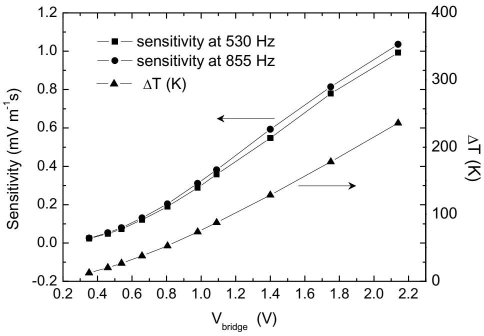

Fig. 5. Sensitivity and wire overheating as a function of the voltage applied to the bridge. The sensitivity is referred to the bridge output voltage.

4. Conclusions

A low voltage acoustic particle velocity (APV) sensor with the pre-amplifier integrated on the same chip has been proposed. The chip has been designed and fabricated with a commercial CMOS process followed by a simple and low cost post-processing procedure. The sensing structure consists of four wires arranged in a Wheatstone full-bridge configuration. In the frequency band 20 Hz - 10 kHz, pre-amplifier input referred noise of 2.4 nV/sqrt(Hz) and sensor detection limit of about 80 dBa have been measured with a bridge voltage of only 2.2 V. The integration of the read-out electronics with the sensing structures on the same chip constitutes a significant improvement in the state of the art of APV sensors.

Acknowledgements

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