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A Study for High-Sensitive and Wideband FET-Based Ultrasound Receiver Directly Driven by Piezoelectric Effect

圧電効果直接駆動による FET 型高感度・広帯域超音波受信器の検討

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1. Introduction

In a situation requiring piezoelectrics having an improved property for seeking high performance in its application such as acoustic wave detection, there is a wide agreement that few technology options are available, even if applying a relaxer that is the one successfully resulted from possible approach of a material exploration, because of its low Tc and Ec. Among such a dilemma allowing use of over 50-year-conventional PZT, recent study showed a novel pressure sensor using piezoelectric materials for a gate of an organic semiconductor thin-film transistor, and a field-effect transistor having a similar structure to that was also studied to indicate an improvable applicability through simulating its properties. These transistor-based pressure sensors are characterized by direct control of a semiconductor channel with charges generated from piezoelectric effect, which leds the assumption of this study expecting ultrasound receiving with high sensitivity, a wide bandwidth and a high dynamic range particularly by the FET-based sensor. Such receiving is promising for highly performable application to eg. medical image diagnosis and non-destructive test, which need sensitivity to capture weak and wideband ultrasound echoes ranging its frequency from fundamental to harmonics.

In this report, we propose a structure possessing direct coupling of PZT to a gate of a MOS-FET chip (PZT-FET) as an ultrasound receiver, and aim at evidencing those above characteristics by observing its acoustic properties by comparing those with conventional PZT-based ultrasound receiving.

2. Device and Method

Fig.1 shows a picture of the experimental setup, in which the acoustic properties of the PZT-FET are observed in water by an ultrasound transducer (PRECISION ACOUSTICS Inc.). Due to its resonant frequency of 15 MHz, the transmitting power is regulated by tuning excitation voltages to be constant over all frequency range measured. The receiver (PZT-FET) is prepared by wiring anode of a PZT slip of 40 μm-thickness and a gate of an NMOS-FET commercially available. **Fig.2** shows the PZT-FET used in the experiments and its equivalent circuit. The distance between the PZT-FET and the transducer is 5 cm. The transmitting wave was intermittent 8-cycle burst (**Fig.3**) to observe near single frequency response of PZT-FET. The frequency of transmitted ultrasounds ranges from 1 MHz to 20 MHz. Output of the PZT-FET is recorded by a drain voltage, which is determined by IV conversion of a source-drain current with a 10 MΩ resistor.

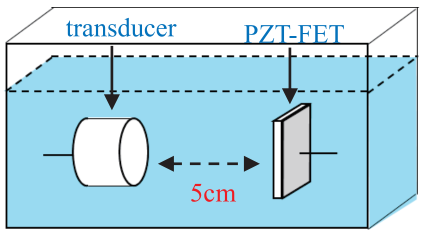
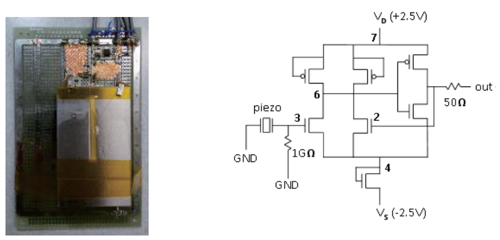


Fig. 1 Experimental set-up



(a) (b)

Fig. 2 Structure of the PZT-FET (a) and equivalent circuit (b)

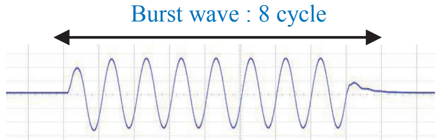
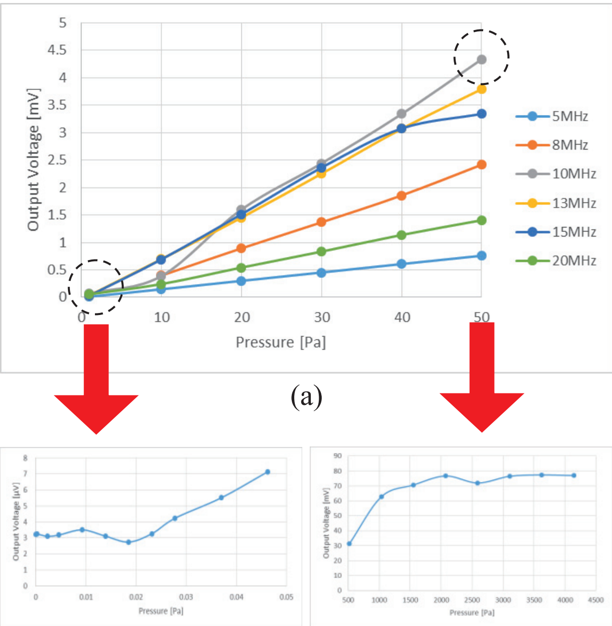


Fig. 3 Transmitted waveform

3. Experimental Result

Fig.4 shows the acoustic pressure dependence of the receiver output measured by varying transmitting frequency and with +- 3 V biasing.

Fig.5 shows the frequency characteristic of the receiver measured under the acoustic pressure of 50 Pa and with +- 3 V biasing.



(a)

(b) (c)

Fig. 4 The receiver output vs. input acoustic pressure. (a) Primary pressure range observed at 10 MHz, (b) narrow scale range at 0-0.05 Pa, (c) extend scale range at 500-4200 Pa

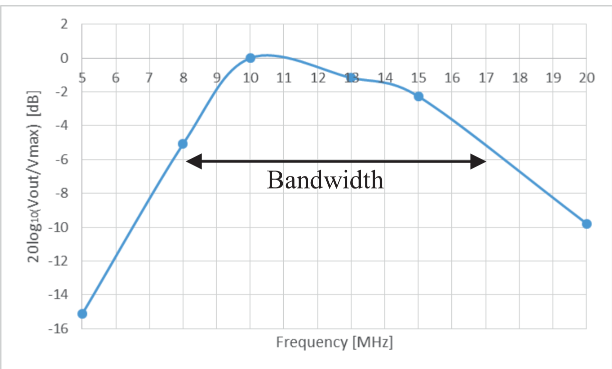


Fig. 5 Frequency characteristic of the receiver. Transmitted acoustic pressure = 50 Pa

4. Discussion

Fig.4(a) shows near linearity of the receiver outputs with respect to the transmitted acoustic pressure for all frequency observed. Possible 1/4 λ resonance frequency (9.6 MHz) calculated from the thickness of the PZT used was consistent with the observation giving maximum at 10 MHz. Linear dynamic range of the receiver under this frequency is determined to be 95 dB (Pa_{min}=0.018, Pa_{max}=1000) that would be tenable to use for a signal displayed for 16-bit gradation. While, the minimum pressure detectable was 0.018 Pa, realization of which is very difficult for a conventional PZT transducer. General trade-off relation for the two above properties enhances excellence of the receiver.

Frequency property in Fig.5 shows the -6 dB specific bandwidth of 100% higher than that of typical PZT. This is due to possible response of the receiver outside the resonance frequency. Those receiver properties thus observed are attributable to the direct drive of FET by piezoelectric charges on the gate, strength of which does not depend only on the resonance but acoustic pressure. So long as it keeps generating the charges, the FET would work with a certain biasing. Accordingly, the receiver properties will be able to expand towards further improvements by using relaxer having higher piezoelectricity than PZT.

5. Conclusion

The PZT-FET proposed in this study performed excellent ultrasound receiving with high sensitivity, high dynamic range and with wideband properties. They were evidenced by those observations, which could not be given by a conventional PZT transducer, and were attribute to the direct drive of FET by piezoelectric charges.

Acknowledgment

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