Displacement of Microparticles on Surface Acoustic Wave Delay Line using High RF Power

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Abstract — **In this paper we investigate the displacement of microparticles deposited on the acoustic path of a surface acoustic wave delay line. The diameter of the targeted particles is between 0.3 µm and 10 µm. The device used is based on Rayleigh waves and builds on 128°YX-$LiNbO_3$ piezoelectric substrate. The displacement is achieved by applying a radio-frequency signal with a high power level superior to 30 dBm at approximately 100 MHz. Particles originates from the fume of a burning candle with diameter smaller than 2.5 µm, and particles of silicon carbide in the vicinity of 17 µm and 5 µm are tested.**

Keywords — Surface Acoustic Wave, delay line, high power radio-frequency signal, microparticle

I. Introduction

Fine-particle pollution has become a worldwide problem during the last decades. Particles with an aerodynamic diameter smaller than 10 µm and 2.5 µm, respectively PM10 and PM2.5, are a subject of great interest since it has been demonstrated that they could be considered as a major threat for human health [1]. Sensing devices used for their survey suffer from soiling. It is therefore necessary to develop a dedicated system for the cleaning of such devices.

On another issue, these types of microparticles can stick on the image sensor of digital single-lens reflex camera (DSLR). Due to the difficulty to handle the image sensor, cleaning these microparticles is a big challenge. Since the early 2000's the major manufacturers of DSLR have developed several dust reduction systems for removing particles stuck on the image sensor. One proposed solution, known as ultrasonic dust removal, is based on a semi-rigid piezoelectric sheet bonded to a transparent plastic film used as filter [2]. Such system turns the plastic film into vibration at frequency between 25 kHz and 50 kHz in order to remove the microparticles.

To address these needs, we investigated the possibility of removing PM20 and PM2.5 by using surface acoustic waves (SAW) delay line.

Rayleigh waves have already been successfully used for moving [3] and positioning [4] drops of liquids as well as single cells in liquid [5]. Here we report our investigation on the possibility to move dry microparticles by using this type of acoustic waves. Since the SAW radiation force is directly linked to the power level of the radio-frequency (RF) signal that drives the device [6], the absolute maximum RF power of the delay line has been characterized.

In section II, the experimental setup for characterizing the absolute maximum rating of the SAW devices is described. Section III is devoted to the microparticles displacement results.

II. Particles Removal System

In this section, the setup designed for driving a SAW delay line with high RF power is described. The design parameters of the tested device are given and its absolute power limitation is identified.

A. Measurement setup

A schematic representation of the system made for measuring the absolute power limit of a SAW device is reported on Figure 1.

The RF signal is amplified by a series of RF amplifier and can reach a maximum power of 40 dBm. S-parameters (S21 and S11) of the device under test (DUT) are obtained by using two commercial bidirectional coupler with high RF power resilience. Particular attention must be paid to the S11 parameter to ensure that the impedance matching between the last RF amplifier and the SAW delay line is optimum. The tested device is bonded in a ceramic package with epoxy glue and wire bonded with gold wires. Afterward, the DUT is mounted on a dedicated PCB. During the entire test, the chip is not monitored in temperature.

Regarding to the RF power level considered for this experiment and the SAW device optimum frequency, the impedance matching of the SAW device input cannot be realized by using standard lumped elements. That's why impedance matching is taken into account during the design step of the DUT.

If the RF power level is higher than the DUT is able to withstand, the device will break. In such case, the RF power amplifiers can be damaged by the reflected power at the input of the DUT because the impedance matching is not anymore optimum. A dedicated analog system is measuring in real time the reflected power at the input of the DUT. If this latter is higher than a threshold chosen by the user, the RF amplifiers power supply is cuted-off. Furthermore, the entire measurement system and the increasing of the RF power are monitored in order to ensure the repeatability of the tests.

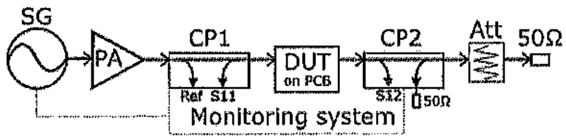

Fig. 1. Schematic representation of the measurement system

B. Measurement of the absolute power limit

The design parameters of the Rayleigh based delay lines used in this work are given in Table 1. A double-electrode configuration has been chosen in order to reduce the triple transit phenomenon [7]. Since the diameter of the targeted particles is between 0.3 µm and 10 µm, the wavelength has been selected to get the electrode width approximately in the center of this range. Impedance matching has been taken into account during the design process.

When a high power signal (higher than 30 dBm) is applied to a SAW transducer, a stress-migration is induced inside the electrodes and may results in the degradation of the device [8]. Such phenomenon is known as the acoustomigration and mostly depends on the design of the electrodes and the metal used for its fabrication [9][10]. To evaluate the power durability, a mean time to failure (MTTF) is usually defined with a variation of the bandwidth or of the insertion losses of the DUT as criterion. Here, the absolute power limit of a SAW device is defined as the RF power level for which the MTTF is lower than 1 s. We took as breaking criterion a variation of the input reflected signal higher than 15 dB.

The frequency of the RF signal is chosen so that the reflected power at the DUT input is as low as possible to prevent any degradation of the RF power amplifier. The RF power level is increased by 0.1 dBm/s from 0 dBm until the failure of the device is reached. About ten devices have been tested in order to get a mean value.

TABLE I. PARAMETERS OF THE TESTED DELAY LINE

Parameter	Value
Piezoelectric substrate	128°YX-$LiNbO_3$
Metallization	Aluminum
Metallization thickness	300 nm
Wavelength λ_0	~ 35 µm
Central frequency	~ 100 MHz
Fingers per wavelength	4
Metallization ratio *a/p*	0.5
Acoustic aperture	43 λ_0
Transducer length	30 λ_0
Gap length	74 λ_0

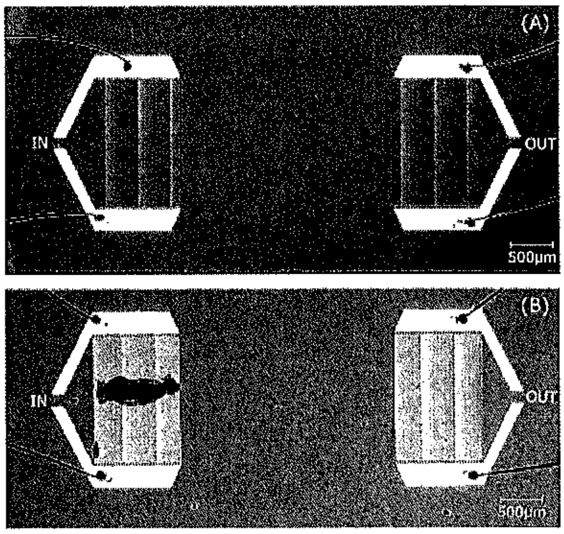

Fig. 2. View of a SAW delay line (A) before and (B) after the test

Figure 2 presents a view of a DUT before and after it reaches the absolute power limit point. We found that this point is approximately 36.8 dBm. We notice that the DUT always broke in the middle of the input transducer. Since an arc discharge could be seen during the test, we may infer that this kind of device failure consists in an electrical breakdown.

In order to avoid the degradation of the device during the removal of the particles, the maximum RF power has been set below this absolute limit, at 35 dBm.

III. Displacement of Microparticles

In this section, the displacement experiments of microparticles using the previously described SAW device are reported. Particles of silicon carbide (SiC) with two different diameters are tested: one type smaller than 17 µm and another type smaller 5 µm. Particles generated from the fume of a burning candle with diameter smaller than 2.5 µm are also tested.

A. PM20 removal experiments

SiC particles smaller than 17 µm and 5 µm of diameter are deposited on the acoustic path of our device. The RF power is slowly increased from 0 dBm until a displacement is observed.

The particles smaller than 17 µm have been partially removed from the gap of the DUT after 3 minutes at 33 dBm. Figure 3 exposed a view of the DUT before and after this test. Even at higher power, and after more time, no further displacement can be observed. This behavior could be explained by the wavelength of the DUT, initially designed for targeting particles smaller than 10 µm.

The particles smaller than 5 µm starts moving at 22 dBm. They are slowly unhooked from the substrate and successfully moved out of the DUT gap until they are stopped by the output transducer.

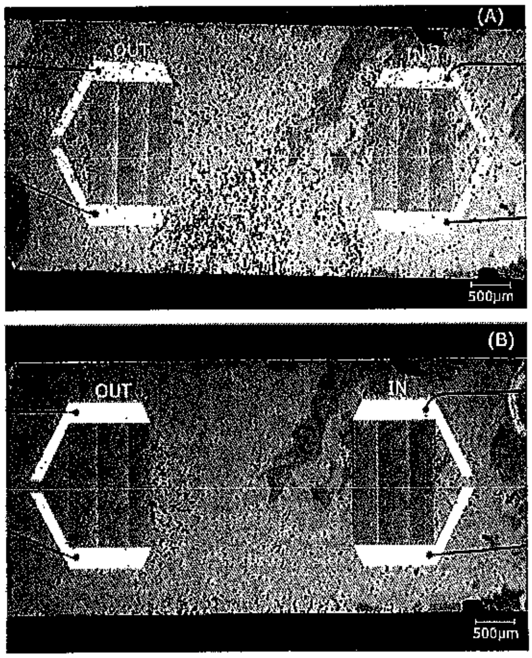

Fig. 3. View of a SAW delay line covered with microparticles of SiC smaller than 17 µm, (A) before and (B) after test

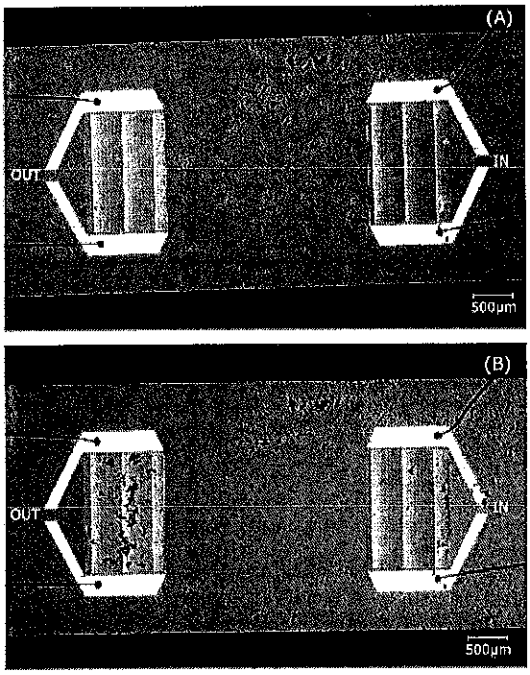

Fig. 4. View of a SAW delay line covered with microparticles of SiC smaller than 5 µm, (A) before and (B) after test

The particles are completely moved out of the DUT gap after 20 s at 31 dBm. Figure 4 expose a view of the DUT before and after this test. The particles have been moved and stopped by the output transducer, but a few particles remain on the gap of the DUT. We assume that this behavior is due to the abrasive characteristic of these particles initially used for polishing substrate. Some of them could be partially sunk on the substrate and cannot be removed by using a RF signal.

B. PM2.5 removal experiments

Particles generated from a burning candle are deposited on the acoustic path of the DUT in order to investigate the displacement of particles smaller than 2.5 µm [11]. The experimental procedure used is identical to the precedent experiences.

At 17 dBm, the particles start moving and, after increasing the RF power, the displacement accelerates. Figure 4 exposed a view of the device before and after a test at 30 dBm during 30 s. The particles have been successfully moved out of the acoustic path of the DUT.

After a few seconds of test we can observe that the particles start acting like a fluid. The melting point of the paraffin wax used is set at 45°C. Since it has been demonstrated that a RF signal of 33 dBm can heat a droplet of water at 39°C [12], the fluid like behavior of wax particles could be explained by this effect. If the temperature of the particles is higher than 45°C the microparticles of wax are turned into a liquid.

Furthermore, the temperature of the device rapidly increased when the signal is transmitted [13]. By measuring the central frequency shift induced by thermal effects, we can estimate this self-heating by using the temperature coefficient of frequency (TCF) of the device's substrate. We assume that the global self-heating of the DUT at 30 dBm is approximately 22°C from the ambient temperature of about 25 °C, enough for turning the particles of wax into a liquid. This estimation is consistent with the particles melting described previously.

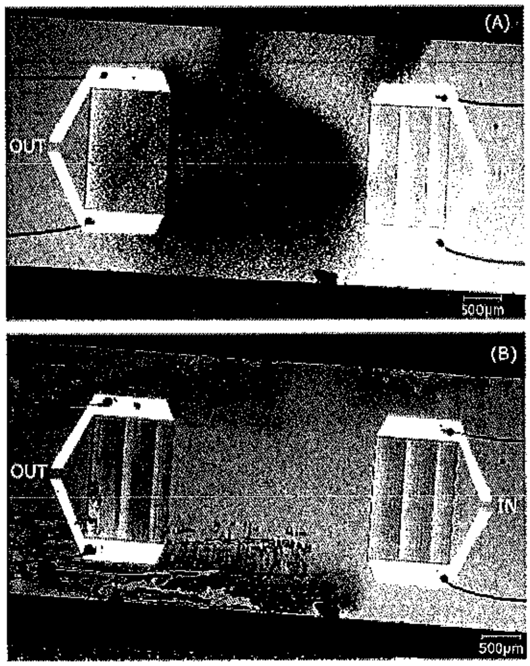

Fig. 5. View of a SAW delay line covered with microparticles smaller than 2.5 µm generated from a burning candle, (A) before and (B) after test

IV. Conclusion

The displacements of microparticles by using a high power RF signal (> 30 dBm) have been experimentally demonstrated. The diameter of the targeted particles is between 0.3 µm and 10 µm. The device used in this work is a SAW delay line based on Rayleigh waves and build on 128°YX-$LiNbO_3$. Particles of silicon carbide smaller than 17 µm have been partially moved out of the DUT gap after 3 minutes at 33 dBm. Same types of particles smaller than 5 µm have been more efficiently moved out of the DUT gap after 20 s at 31 dBm. Such experiment shows a link between the size of the targeted particles and the SAW wavelength.

Particles smaller than 2.5 µm, generated from the fume of a burning candle, have also been moved out of the acoustic path after 30 s at 30 dBm. The fluid-like behavior of these particles is explained by the self heating of the device.

This work demonstrates experimentally the possibility of using a SAW device for removing microparticles from a surface. Further experiments with other types of particles deposited on the active surface of a particle sensor are in progress in order to show the effectiveness of this technique for cleaning such device.

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References

[1] G. Rusu-Zagar, C. Rusu-Zagar, I. Iorga, and A. Iorga, "Air Pollution Particles PM10, PM2,5 and the Tropospheric Ozone Effects on Human Health," *Procedia - Social and Behavioral Sciences,* vol. 92, pp. 826-831, 2013/10/10/ 2013.

[2] J. R. Martin, "Apparatus for maintaining clean optical surfaces in process environments," U.S. Patent 4 387 973, Jun. 14, 1983.

[3] B. A. Korshak, V. G. Mozhaev, and A. V. Zyryanova, "Observation and interpretation of SAW-induced regular and chaotic dynamics of droplet shape," in *IEEE Ultrasonics Symposium, 2005.*, 2005, vol. 2, pp. 1019-1022.

[4] J. Bennes *et al.*, "Detection and High-Precision Positioning of Liquid Droplets Using SAW Systems," *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control,* vol. 54, no. 10, pp. 2146-2151, 2007.

[5] F. Guo *et al.*, "Three-dimensional manipulation of single cells using surface acoustic waves," *Proceedings of the National Academy of Sciences,* vol. 113, no. 6, pp. 1522-1527, 2016.

[6] F. Tomohiko and K. Jun, "Experimental consideration of droplet manipulation mechanism using surface acoustic wave," *Japanese Journal of Applied Physics,* vol. 54, no. 7S1, p. 07HE06, 2015.

[7] D. Morgan, *Surface acoustic wave filters: With applications to electronic communications and signal processing*. Academic Press, 2010.

[8] H. Schmidt, R. Kunze, M. Weihnacht, and S. Menzel, "Investigation of acoustomigration effects in Al-based metallizations," in *2002 IEEE Ultrasonics Symposium, 2002. Proceedings.*, 2002, vol. 1, pp. 415-418 vol.1

[9] M. Pekarcikova, M. Hofmann, S. Menzel, H. Schmidt, T. Gemming, and K. Wetzig, "Investigation of high power effects on Ti/Al and Ta-Si-N/Cu/Ta-Si-N electrodes for SAW devices," *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control,* vol. 52, no. 5, pp. 911-917, 2005.

[10] S. B. Menzel *et al.*, "A novel copper damascene technique for power loaded SAW structures," *MRS Proceedings,* vol. 833, p. G3.13, 2011, Art. no. G3.13.

[11] P. M. Fine, G. R. Cass, and B. R. T. Simoneit, "Characterization of Fine Particle Emissions from Burning Church Candles," *Environmental Science & Technology,* vol. 33, no. 14, pp. 2352-2362, 1999/07/01 1999.

[12] N. Ohashin and J. Kondoh, "Temperature control of a droplet on disposable type microfluidic system based on a surface acoustic wave device for blood coagulation monitoring," in *2015 IEEE International Ultrasonics Symposium (IUS)*, 2015, pp. 1-4.

[13] C. Huck, H. P. Zidek, T. Ebner, K. C. Wagner, and A. Wixforth, "Thermal characterization of Surface Acoustic Wave devices," in *2013 IEEE International Ultrasonics Symposium (IUS)*, 2013, pp. 1089-1092.