Journal of Electrostatics 72 (2014) 136–139

Contents lists available at ScienceDirect

Journal of Electrostatics

journal homepage: www.elsevier.com/locate/elstat

Generation and detection of electromagnetic field with charged material oscillation

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ARTICLE INFO

Article history:
Received 2 February 2013
Received in revised form
6 November 2013
Accepted 12 December 2013
Available online 13 January 2014

Keywords:
Static electricity
Electric field
Sound wave
Measuring technology
Distribution

ABSTRACT

We generated an electromagnetic field using the spatial oscillation of a charged material such as a polyimide film. The film was vibrated with acoustic waves at 1 Hz–1 kHz. For charged films, changes in electric field intensity with acoustic wave irradiation were detected using an antenna. The electric field intensity and phase were found to be related to the surface voltage and electrical polarity. The surface potential distribution matches the electric field distribution that was measured by scanning the local excitation. These results indicate that this phenomenon can be used to measure the electrical properties of charged materials.

1. Introduction

Electromagnetic (EM) techniques are widely applied as signal detection probes [1] and power sources [2]. EM properties also lead to the development of novel techniques for the characterization of materials. The detection of electrical properties in piezoelectric materials using acoustically stimulated electromagnetic radiation was reported by K. Ikushima et al. [3,4]. The EM waves in piezoelectric and magnetic materials were generated using ultrasonic irradiation. In addition, unique EM emission techniques using acoustic waves were demonstrated for space charges in air and granites [5–7]. Thus, techniques for generating EM fields would be essential in measuring material properties. Here, we demonstrate a unique method for probing the electrostatic charge properties of insulators via acoustic waves.

Many electrostatic measurement techniques and evaluation methods have been developed [8–14]. Some electrostatic field measurements can quantify surface potential on a material without contact. Among them, electro-optical effects such as the Pockels [15,16] and Kerr effects [17,18] have been developed into effective techniques in order to measure electrostatic charge at a distance from a target. However, since these effects are very small in air, it is necessary to increase the effects by using a crystal or gas. When detecting the electrostatic charge in environments such as a manufacturing process, the use of any medium other than air is a disadvantage. In this study, we propose a new workable method for measuring the electrostatic charge utilizing an EM generation and detection technique with acoustic waves. The concept of the charged material oscillation (CMO) method for electrostatic charge detection is as follows: (i) a positive charge is assumed to exist on a material, (ii) the charged material is vibrated physically by an acoustic wave, (iii) the electrostatic charge on the material is oscillated spatially, and (iv) an electric field is generated by the charge oscillation, which induces the EM field. In this manner, an EM field is generated by a charged material through acoustic irradiation. The electrostatic charge is detected by measuring the acoustically induced electric field.

2. Experimental setup

The experimental setup for detecting electric field generated by charged material oscillation is shown in Fig. 1(a). The system consists of a means of generating acoustic waves and measuring electric fields. In order to generate an acoustic wave, a function generator was connected to a speaker. The amount of displacement of the speaker actuator was about 1.1 mm. For EM field detection, the antenna was used a floating monopole type, which was a bared central conductor of a coaxial cable at 100 mm length, and it was connected directly with a preamplifier (60 dB gain) and digital oscilloscope. Alternatively, a lock-in amplifier was used to reduce

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http://dx.doi.org/10.1016/j.elstat.2013.12.005

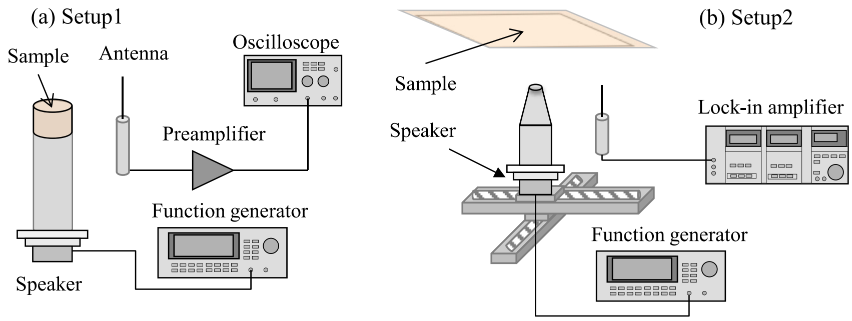

Fig. 1. Experimental setup for (a) detecting electric field generated by charged material oscillation and (b) measuring surface potential distribution of sample film.

noise and improve the sensitivity of the measurement system. We used a polyimide film of 100 μm thickness and 80 mm square in size. The resistivity of the insulating polyimide film was greater than 1×101^7 Ω cm. The sample was charged by corona discharge using a needle-type corona source. The voltage applied to the electrodes was 8 kV and the load current was 500 μA. The sample was mounted on a flat grounded plate and placed face to face with the needle when charging the sample. The surface potential of the sample was controlled over the range of 10 V–2 kV by adjusting the distance (2 cm–10 cm) between the needle and the sample, and by adjusting the irradiation time (1–10 s). The sample was wrapped around the circumference of a hollow, open-ended cylinder using glue, under a tension of about 20 g. So, the cylinder does not vibrate, only the sample is vibrated by acoustic waves. The bottom face of the cylinder was fixed on the speaker without affecting the actuator motion of the speaker. The sample was placed 50 mm away from the speaker; a square wave in the frequency range of 1 Hz–1 kHz was applied. The antenna was placed 50 mm from the sample. In this manner, the electric field intensity and phase were measured after the charged film was vibrated by acoustic waves. The surface potential was measured simultaneously using a surface voltmeter in order to quantify the electric charge.

The experimental setup for measuring surface potential distribution of sample film is shown in Fig. 1(b). The side of sample was fixed with a jig, and the sample was placed above the speaker. The focused sound wave was generated by the structure of the narrow outlet with a plastic cone-shaped speaker that was placed at 2 mm from the sample. The speaker was moved at 5 mm intervals in the range of 0–70 mm by an automatic *x*–*y* stage.

3. Results and discussion

Fig. 2 shows the change in electric field intensity with acoustic wave for charged and uncharged polyimide films, and the change of signal with (c) sound irradiation at 1 Hz pulse. In the uncharged film, we found no discernible change in the electric field intensity with the application of an acoustic wave. In the charged film, where the measured surface potential of the entire surface was between 1.5 and 2.0 kV, a large change in the electric field intensity was observed, with an average signal variation of about 1 mV. The changes occurred just after acoustic irradiation with an impulse response. The result shows that the sample spatial vibration occurred at the input pulse wave signal where the electric field change was detected. This implies that the change in the electric field was induced by the vibration of the charged film because of the changes in the electromagnetic field generation efficiency with charge oscillatory displacement.

Fig. 3 shows the frequency dependence of the electric field intensity using 1 kHz acoustic wave applied to uncharged and charged films. In the uncharged film, the small signals at 1 kHz corresponded to noise in the speaker, as shown in Fig. 3(b). In charged films, an increase in the electric field intensity at 1 kHz was observed, corresponding to the fundamental waves of the electric intensity, respectively, as shown in Fig. 3(a). This result implies that the frequency of electric field was the same as the spatial vibration of charge. In other words, the frequency of the induced EM field can be controlled by the acoustic wave properties. Therefore, small signals of electric field can be detected by a lock-in amplifier in the same frequency as the vibration of the object. In this study, we can

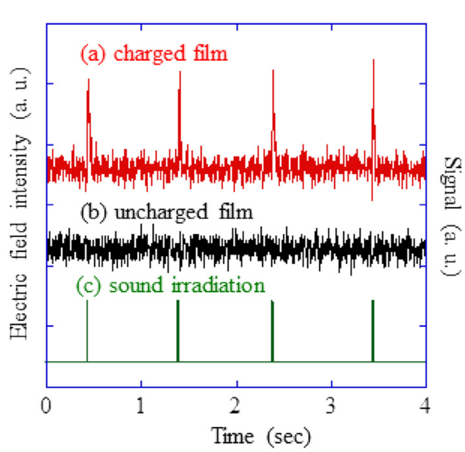

Fig. 2. Change of electric field intensity with an acoustic wave for (a) charged and (b) uncharged polyimide films, and change of signal with (c) sound irradiation at 1 Hz pulse.

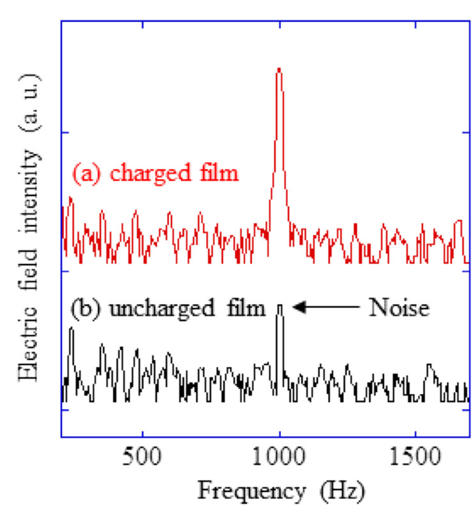

Fig. 3. Frequency dependence of electric field intensity with an acoustic wave at 1 kHz in (a) charged and (b) uncharged polyimide films.