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Original Research Paper

Interdigital transducer generated surface acoustic waves suitable for powder transport

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ABSTRACT

Recently, in the electronics and pharmaceutical industries, miniature devices that can transport a tiny amount of dry powder with a particle size of 100 μm or less are desired. We therefore focused on a surface acoustic wave (SAW) device, and we experimentally studied an interdigital transducer (IDT) that generates the SAW. As a result, it was found that an IDT with a 2-mm pitch size at a 90° inclination angle, against the perpendicular direction of a piezoelectric wafer (127.8° *y*-rotated *x*-propagating $LiNbO_3$) orientation flat, had a high efficiency of copper powder (about 100-μm particle size) transport. Then, to investigate the availability of a SAW actuator with this highly efficient IDT, we fabricated a miniature feeder (13-mm height × 18-mm width × 78-mm length) mounted with a hopper on the SAW actuator and carried out a powder supply experiment. As a result, it was found that, when 1 W of electric power was applied to the IDT of the feeder, the powder supply capability of the feeder was about 18 mg/s. From this fact, it was experimentally shown that a SAW actuator with a highly efficient IDT has a great potential to control dry powder with superior accuracy.

1. Introduction

Recently, in the electronics and pharmaceutical industries, there has been a need for physical operations, such as the transportation and separation of micro metal powder for mixing it with semiconductor encapsulation resin and organic compound powder for making medicine. However, it is difficult to efficiently and accurately handle such powder because it can behave not only as a solid but also as a liquid or gas. Therefore, in many industrial plants, the powder must be handled using conventional experimental rules. This conventional approach makes it impossible to transport a tiny amount (from several hundred μg to several mg) of dry powder with a size of 100 μm or less if a general-purpose conveyor or feeder that has been miniaturized is used.

In related studies on powder transport, a vibratory feeder [1,2], a screw conveyor [3], an ultrasonic wave device [4], and so on were reported. For these devices, only the ultrasonic wave device was studied for transporting a tiny amount of dry powder. However, since such a device consists of piezoelectric multi-layers, its manufacturing process is complicated. We therefore focused on a surface acoustic wave (SAW) device with a simple structure fabricated by photolithography. Incidentally, SAW devices are commonly used as IF (intermediate frequency) and RF (radio frequency) filters for mobile phones. The SAW is an acoustic wave propagating along a surface of an elastic body, and it is generated by applying a high-frequency voltage to an interdigital transducer (IDT) on a piezoelectric substrate. When an object is placed on the propagating surface, the SAW acts on the object and drives it while attenuating. This phenomenon is utilized in SAW actuators. In related studies on SAW actuators, liquid flow has been mainly reported [5–11], and there are very few reports on solids moving [12].

The most interesting characteristic of a drive system that uses SAWs is that the flow direction of a liquid is opposite the moving direction of a solid, including powder. Concretely, liquids flow in the SAW propagating direction, i.e., toward the SAW downstream side, and solids move toward its upstream side. These two types of transport are caused by longitudinal wave radiation into the liquid and backward elliptical motion on an elastic body surface, respectively (Ref. Fig. 1). Here, focusing on a feeder (that transports powder on a substrate and makes it fall down a hole in the substrate) as an actuator, we can easily understand that a feeder driven by SAWs cannot be realized because there would be a

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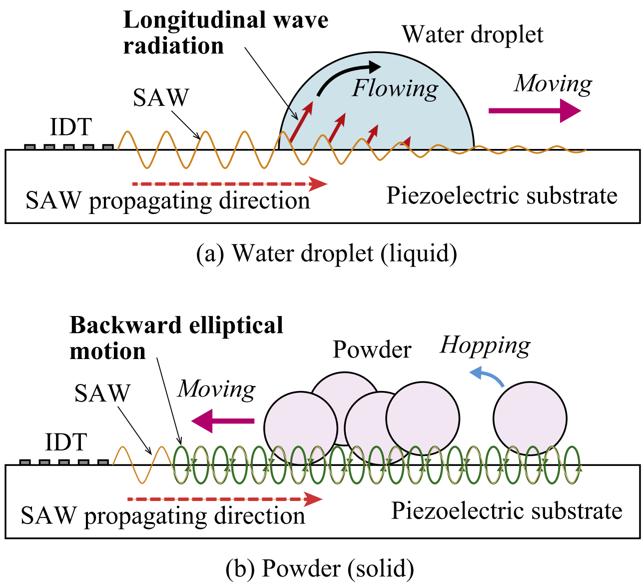

Fig. 1. Object transport mechanism by SAW.

contradiction. This is because the hole in which powder falls down must be located on the generation source side of the SAWs, and thus, the SAWs cannot reach the powder through the hole. From examples like this, it was found that powder transportation toward the SAW downstream side, not the upstream side, has a big advantage when designing various actuators and systems involving them. Therefore, to solve this problem of powder transport direction, we proposed a novel method for SAW actuator driving that does not involve the resonance frequency used conventionally [13]. We then succeeded in transporting powder toward the SAW downstream side by using specific frequencies.

We speculated that the specific frequencies are related to IDT positions located on the piezoelectric substrate, i.e., atomic arrangements on its surface. In this study, we therefore investigated the relationship between IDT location and drive frequency, whose combination can transport powder toward the SAW downstream side, and we evaluated the combination with high transportation efficiency. Moreover, for higher efficiency, we investigated the relationship between the IDT pitch size and the transportation efficiency with the IDT position with the highest transportation efficiency. Incidentally, from our previous study on liquid flow actuators driven by SAWs, it was found that the IDT pitch size greatly influences the transportation efficiency [10]. Finally, on the basis of the obtained results, we fabricated a SAW miniature feeder with a high efficiency IDT and investigated its availability.

2. Interdigital transducer (IDT) location and drive frequency

2.1. Candidate selection of drive frequency on basis of IDT's return loss characteristics

A photograph of four IDTs, prepared to investigate drive frequencies for transporting powder toward SAW downstream sides, is shown in Fig. 2. The IDTs were located at inclination angles θ of 0, 30, 60, and 90° against the perpendicular direction of the orientation flat of a 4-in. piezoelectric (127.8° *y*-rotated *x*-propagating $LiNbO_3$) wafer (see Fig. 3). Here, we chose an IDT shape with a 400-μm stripline pitch (p), a 10-mm aperture (w), and 20-stripline pairs (n).

The IDTs were fabricated by using a semiconductor process. A piezoelectric wafer was used as the starting substrate. The thick-

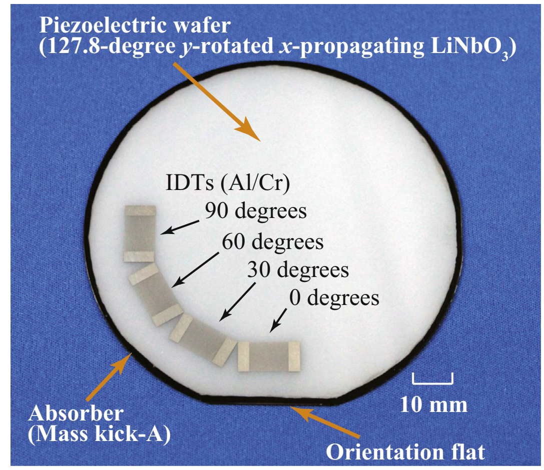

Fig. 2. Photograph of IDTs prepared to investigate drive frequencies for transporting powder toward SAW downstream side.

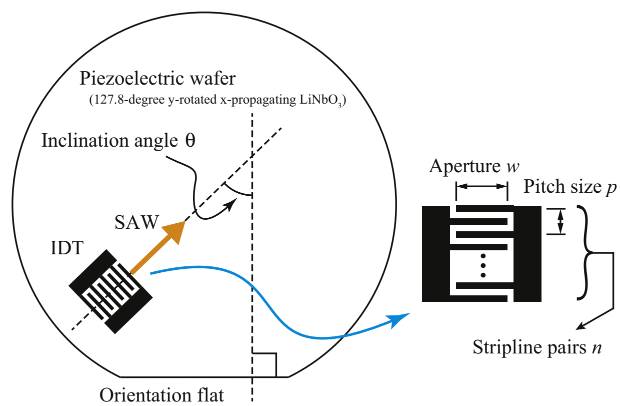

Fig. 3. IDT location and its shape parameters.

ness of the substrate was 500 ± 30 μm, and its surface roughness was 0.3 nm or less. A 50-nm Cr film and a 1000-nm Al film were formed on the wafer by RF sputtering. The Al and Cr films were used as electrode and adhesion layers, respectively. Then, UV exposure was applied to a positive resist (OFPR-800, Tokyo Oka Kogyo Co., Ltd.), and an IDT electrode pattern was transferred from a glass mask. After that, Al and Cr etching was performed in accordance with this pattern to fabricate the IDTs. Incidentally, to prevent SAW reflection from the edge of the wafer, we used hot-melt asphaltic adhesive (Mass kick-A, Furuuchi Chemical Co.) as absorber material. The absorber material was painted on the wafer circumference with a small writing brush, and its thickness was 200 μm or more.

To select candidate drive frequencies for transporting powder toward the SAW downstream side, we investigated the frequency characteristics of the return losses (RLs) of the fabricated IDTs by using an antenna analyzer (AA-230PRO, Rig Expert Ukraine Ltd.). The RL frequency characteristics of the IDTs with inclination angles of 0, 30, 60, and 90° are shown in Fig. 4(a)–(d), respectively. Here, the frequency and the RL are shown on the horizontal axis and vertical axis, respectively. The RL is the logarithmic ratio of the incident electric power P_I to the reflected electric power P_R, i.e., a larger RL means that it is easier to supply electrical power to the IDT.

As seen in Fig. 4(a), at the IDT with a 0° inclination angle, one RL peak was observed at 9.7 MHz, and multiple peaks were then observed at intervals of about 4 MHz in a frequency range from 20.8 MHz. This 9.7 MHz is the conventional drive frequency of IDTs