Transport powder and liquid samples by surface acoustic waves

Xiaoqi Bao[1], Yoseph Bar-Cohen, Stewart Sherrit, Mircea Badescu and Sahar Louyeh*
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA
*Pennsylvania State University, University Park, PA 16802, USA

ABSTRACT

Sample transport is an important requirement for In-situ analysis of samples in NASA planetary exploration missions. Tests have shown that powders or liquid drops on a surface can be transported by surface acoustic waves (SAW) that are generated on the surface using interdigital transducers. The phenomena were investigated experimentally and to generate SAWs interdigital electrodes were deposited on wafers of 128° rotated Y-cut $LiNbO_3$. Transporting capability of the SAW device was tested using particles of various sizes and drops of various viscosities liquids. Because of different interaction mechanisms with the SAWs, the powders and the liquid drops were observed to move in opposite directions. In the preliminary tests, a speed of 180 mm/s was achieved for powder transportation. The detailed experimental setup and results are presented in this paper. The transporting mechanism can potentially be applied to miniaturize sample analysis system or "lab-on-chip" devices.

KEYWORD: Powder and liquid transport, SAW device, lab-on-chip, Sample handling, MEMS.

1. INTRODUCTION

Future NASA missions having in-situ exploration objectives are increasingly requiring analysis of acquired samples to detect and characterize the presence of biomarkers and water, as well as determine the geological content. For these missions, there is a critical need to control the flow of sampled powder for delivery to the analyzers and sieving the particles according to their size. The ability to control the motion of sand grains via traveling surface acoustic waves significantly enhances the sample handling capability in support of future missions and allows for reduction in the required system mass, power and volume. In addition, sample handling mechanisms that transport of liquid drops and particles that eliminate the need for moving parts significantly increase the probability of success of future missions and enable miniaturization of the mechanism to produce micro-fluidic networks. Since the mechanism is based on piezoelectric actuators it can be operated at extreme temperatures from as cold as on Europa and Titan to as hot as on Venus.

We have demonstrated that transporting powder via no macro-moving parts is accomplished by traveling surface acoustic waves (SAW) that are emitted by an Inter-Digital Transducer (IDT). The generated waves were driven at about 10MHz and caused powder to move towards the IDT at relatively high speed with different speeds for different size particles offering the capability to sieve particles. Further, experiments with water drops on the surface adjacent to the IDT made the water flow opposite to the direction of IDT (in contrast to the direction of travel of the powder) and again at relatively high speed. Multiple IDTs can be synchronized and used together to transport water or powder over a larger distance. The fact that the water moves opposite to the IDT location while powder moves in the direction of the IDT allows the device has the potential ability to separate large particles and fluids that are mixed.

2. BACKGROUND

The transportation of particles and fluids is based on the use of surface acoustic waves (SAW) and their propelling effect along the path of the waves. Generally, surface acoustic waves are elastic waves that are

[1] Correspondence: xbao@jpl.nasa.gov

propagating in a shallow layer of about one wavelength beneath the surface of a solid substrate [1]. The surface nature of the wave is shown in Figure 1, where the wave amplitude rapidly decays with depth. To generate SAW we used a piezoelectric plate made of LiNbO3 crystal that was cut with a rotation of 127.8° along the Y-axis. On this plate we sputtered pairs of finger-like electrodes in the form of a grating (see Figure 2) that are used to create alternating electric fields in the gaps between the electrodes. This configuration of a surface wave transmitter is called inter-digital transducer (IDT) and the surface displacement is produced by the piezoelectric material as it contracts or expands when subjected to an alternating electric field. The gap between the fingers of the grating determines the SAW frequency. Driving the generated wave at high amplitudes provides an actuation mechanism where the surface particles move elliptically. The mechanism was utilized to move sliders on the surface in linear SAW motors [2]. The interaction of the SAW to fluids was studied and applications of the mechanism to pumps were reported [3]. In this study, we investigated the capability of the SAW to transport the powder piles and liquid drops on the surface. The SAWs push powder particles on the surface opposite to the surface acoustic wave direction and liquids in the same direction as the SAW.

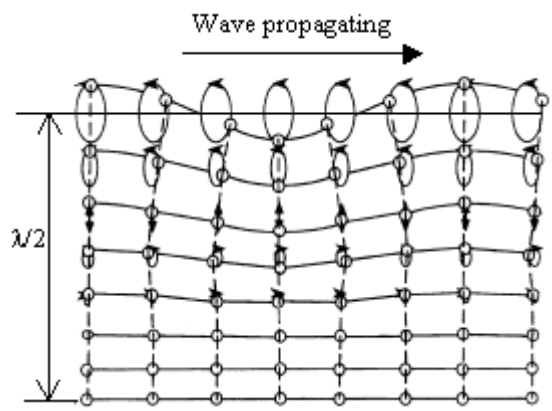

FIGURE 1: A schematic view of the particle displacement along the surface acoustic wave (SAW).

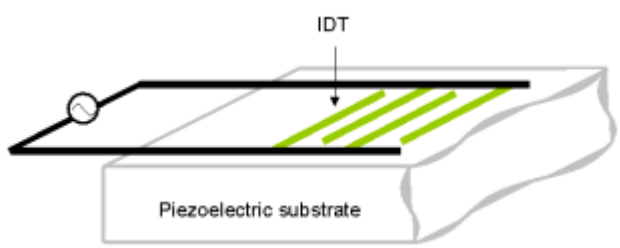

FIGURE 2: A schematic view of an interdigital transducer (IDT) that is used to induce surface acoustic waves.

3. THE TESTED SAW DEVICE

A photographic view of the SAW device that was used is shown in Figure 3. The photo shows four IDTs on the transparent piezoelectric wafer that is made of 128° rotated Y-cut Lithium Niobate crystal wafer with thickness of 1.0 mm. The IDT consists of 20 pairs of 12.5-mm long fingers with 0.4 mm spacing. The distance between two opposite IDT electrodes set is 25 mm. Absorbing resin is placed behind the IDTs to reduce the interference from the waves sent to back direction and reflected from the wafer boundary. The bottom right IDT was the one that was excited in the demonstration tests that we conducted. The IDT was covered with a plastic film to prevent the moving powder from reaching the electrodes. The red line on the

left is a straight wire that we used as a stop in the case the sample was moving to the left. The input admittance of the IDT that we used was measured by an impedance analyzer (HP 4294a) and is shown in Figure 4. The applied voltage in the sample transporting tests was 43.6 V_{RMS}, the frequency was 9.6 MHz and the calculated input power is 28 Watt. We used a video camera to record the transporting actions. It can be seen in the photograph as a ring appearing in the area between the IDTs due to the reflection of the crystal surface. The speeds of sample movements were measured from the frame images of the video.

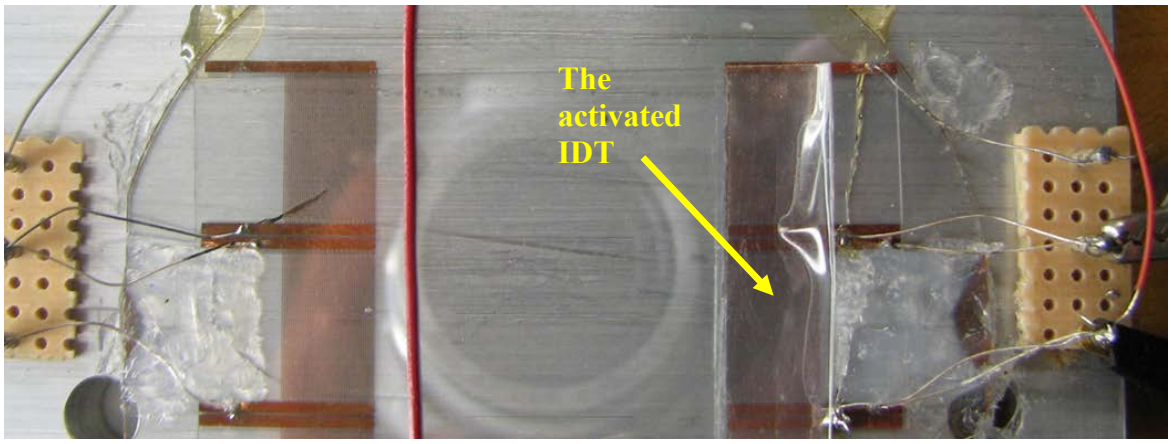

FIGURE 3: A photographic view of four IDTs on two opposite sides 25-mm apart having two on each side. In the following results and data we activated only one IDT.

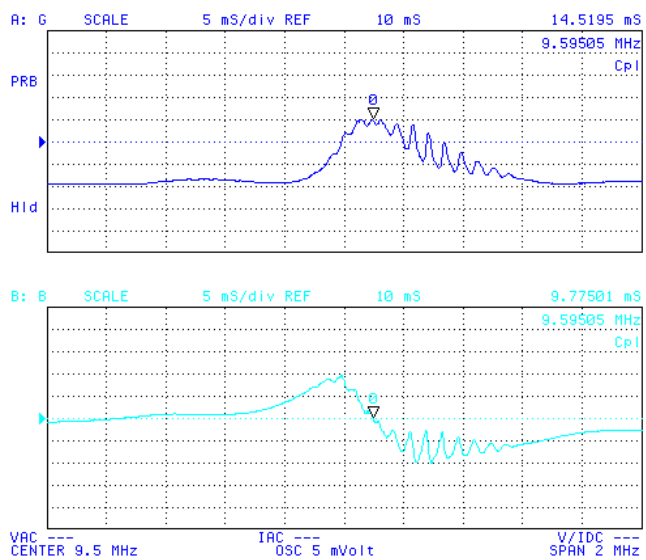

FIGURE 4: Input admittance of the IDT. The up graph is the real part and the low is the imaginary part. In the transportation tests the applied voltage was 43.6 Vrms, the frequency was 9.6 MHz and the calculated Power 28 Watt.

4. EXPERIMENTAL RESULTS

Samples of powder of two different sizes, liquid drops with different viscosities and a powder-water mixture were tested on the SAW device. The powder particles traveled in the opposite direction to the traveling surface waves and therefore they moved towards the IDT location whereas the liquid drops traveled with the waves (see Figure 5) moving away from the generating IDT's.

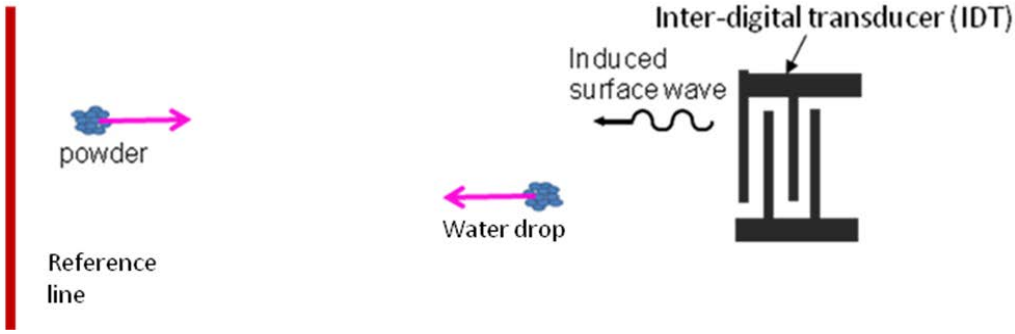

FIGURE 5: A schematic view of the (IDT) that was used to induce SAW and the direction of movement of the wave, water drops and powder particles.

The powder samples were Al_2O_3 powder (#240 grit) with particle size ~50 μm and WCA-12 particles having 50% of the particles in the size range of 7 – 8.5 μm. At the starting point, a small pile of powder was placed on the left next to the red wire and upon activation a video was taken from which we made snapshots as shown in Figures 6 and 7. The frame rate was 30 frames per second. The traveled distance of the larger particles was about 19 mm and the visible powders arrived the IDT at an average speed of ~140 mm/s while most particles moved with a speed of ~60 mm/s. The smaller particles moved a distance of about 18 mm, where the visible powders reached the IDT side at an average speed of about 180 mm/s and most of the particles moved at an average speed of 90 mm/s. The smaller particles moved at a measurably higher speed offering a potential capability to sort the particles by size.

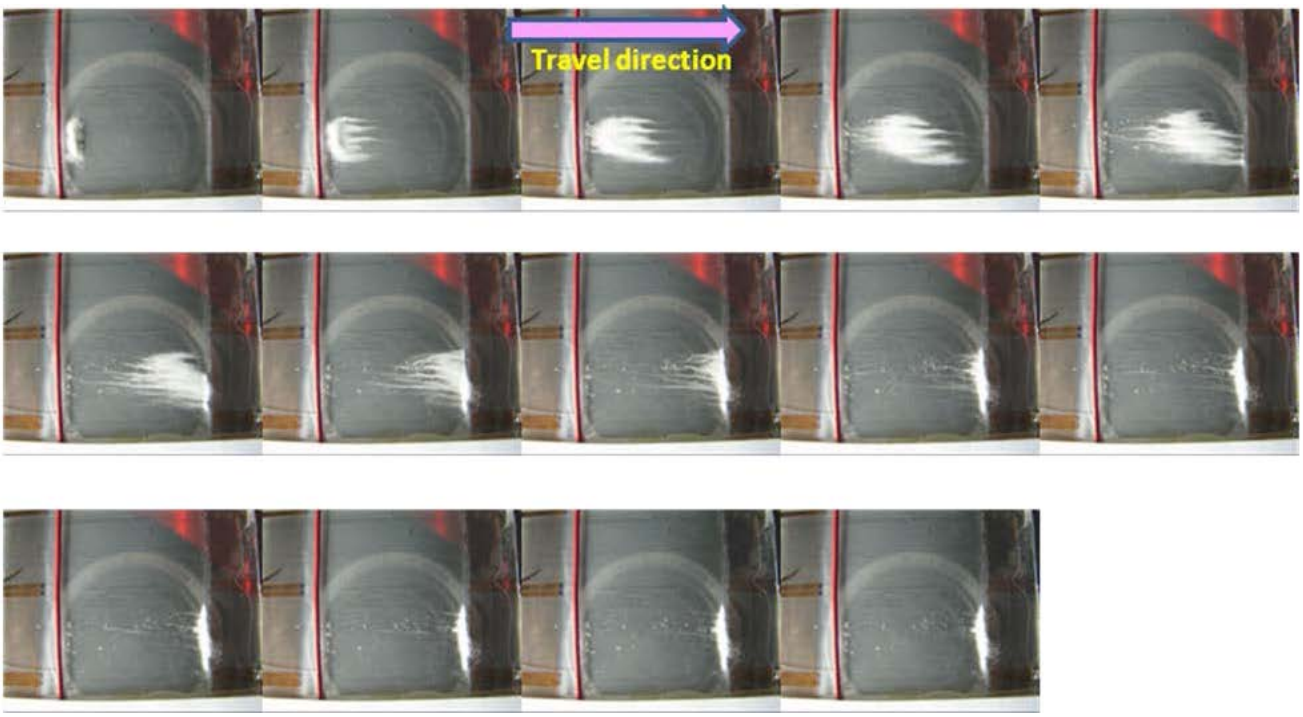

FIGURE 6: Snapshots from the travel of the Al_2O_3 ~50 μm size powder (#240 grit). The frame rate is 30 frames per second.

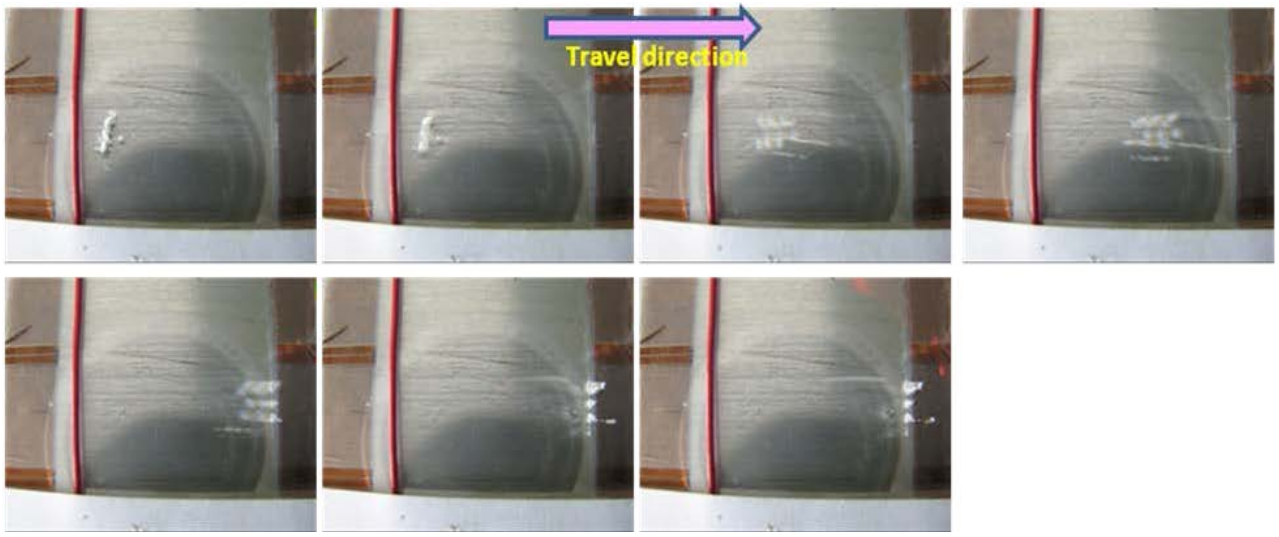

FIGURE 7: Snapshots from the travel of the Al_2O_3 7–8.5 μm size powder (WCA 12). The frame rate is 30 frames per second.

As shown in Figure 8, our experiments with liquid drops on the surface of the piezoelectric plate with IDT, which generated the surface acoustic waves, made drops move in the opposite direction of the IDT (opposite to the direction of transporting powder and particles). The traveled distance that was measured is ~20 mm and tracking the movement of the water drop edge on the recorded video has shown an average speed of ~150 mm/s. As soon as the IDT was activated the water drop was "smeared" over the surface and examining the arrival of the rest of the drop has shown an average speed of ~75 mm/s. In addition, some vaporization of water was observed and it can likely be attributed to the excitation of cavitations in the water.

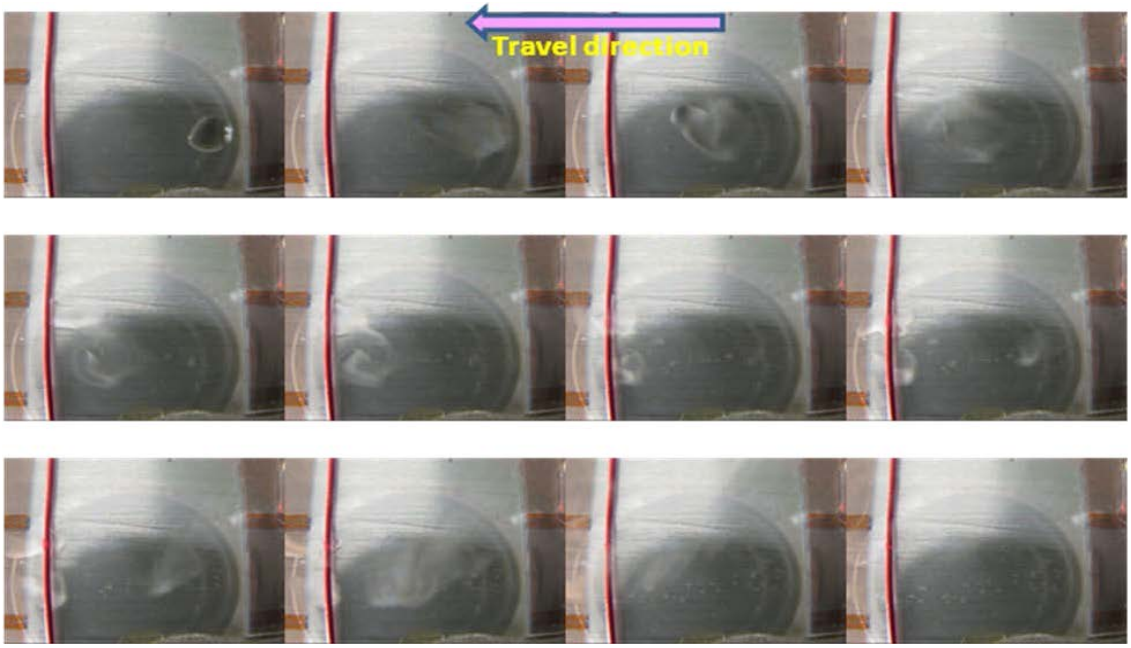

FIGURE 8: Snapshots from the travel water drop along the path of the SAW (from right to left).

It is expected that the speed of liquid movement will depended on the viscosity of the liquid. Primary observations were performed for several easy-to-get liquids or liquids with suspension. The viscosity increases in the following order; ethyl alcohol, water, soybean oil, ketchup and mustard. The results are presented in Figure 9. It is apparent that the moving speed decreases as the viscosity increases.

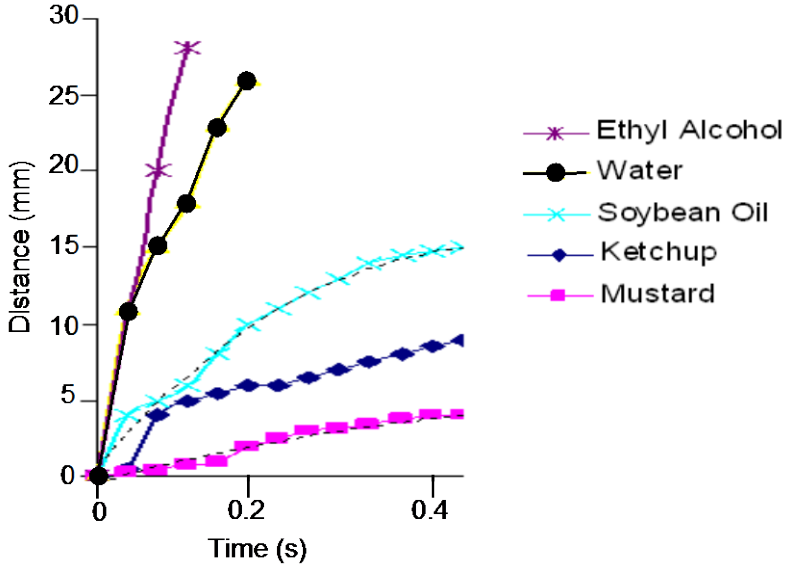

FIGURE 9: Movements of liquids with various viscosities.

Other experiments showed the SAW's were able to move powder-liquid mixtures. The powder is sand with sizes of most particles in 0.1 – 0.2 mm range. The powder/water mixture was in a shape of small clump and saturated by water. Snapshot views from video taken in the experiment are presented in Figure 10. The sand-water clump moved along the SAW propagating direction a distance of ~15 mm in 0.3 second. The averaged speed was ~50 mm/s. The curve showing the distance traversed with the time is presented in Figure 11. We found that the curve could be fit by quadratic function quite well within the first 0 - 0.25 seconds. This implies the mixture was driven by a near constant force in the period. The acceleration was about 342 mm/s^2 and the speed at 0.25 second was around 85 mm/s.

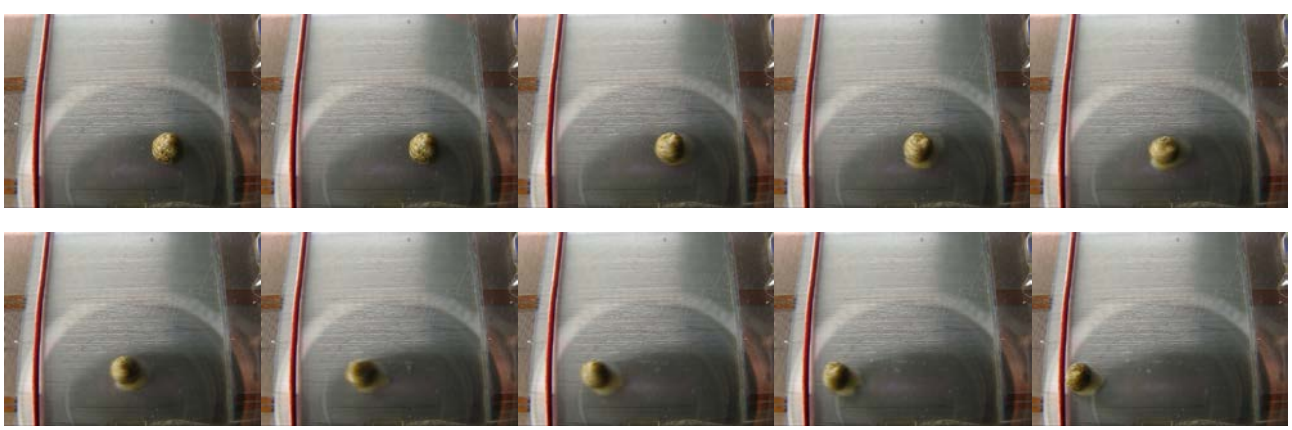

FIGURE 10: Sequence frames from the video of sand-water mixture traveling along the propagating direction of the SAW (from right to left). The frame rate is 30 f/s. The distance between the opposite IDT electrodes is 25 mm.

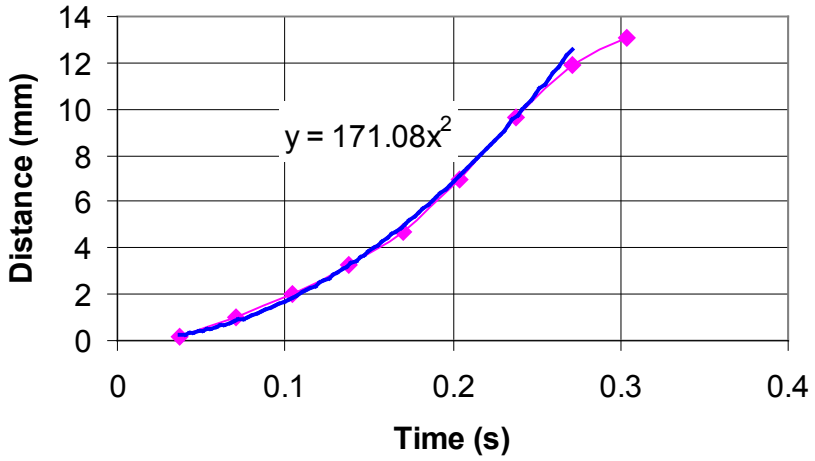

FIGURE 11: The moving distance versus time measured using the sequence frames of the sand- water mixture traveling and the square curve fitting. The speed at 0.25 second is estimated as 85.5 mm/s.

5. SUMMARY

Tests have shown that powders or liquid drops on a surface can be transported by surface acoustic waves. The phenomena were investigated experimentally. Because of different interaction mechanisms with the SAWs, the liquid drops move along the wave direction and the powders were observed to move in opposite direction to the wave. A SAW device made of 128° rotated Y-cut $LiNbO_3$ wafer with interdigital electrodes is able to transport the powers, liquid drops and the mixture effectively. Relatively high transportation speeds were achieved.

The transporting mechanism can potentially be applied to miniaturized sample analysis systems or "lab-on-chip" devices. Due to the wide operating temperature range of the $LiNbO_3$ crystal, the device can be used at extreme temperatures from as cold as on Europa and Titan to as hot as on Venus.

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