Characteristics of Liquids Atomization
Using Surface Acoustic Wave

Minoru Kurosawa, Akira Futami, and Toshiro Higuchi

Dept. of Precision Machinery Engineering, The University of Tokyo,

Hongo, Bunkyo-ku, Tokyo 113, Japan, Fax: +81-3-5800-6968, mkur@pe.u-tokyo.ac.jp

SUMMARY

A novel way to produce dry fog using a surface acoustic wave transducer has been proposed. This atomizer is suitable for miniaturization and for feed very small amount of mist to control atmospheric condition. The device is 4x8x0.6 mm^3 LiNbO$_3$ piezoelectric substrate. High frequency electrical power of 48 MHz is transduce to mechanical vibration using an interdigital transducer. The high frequency mechanical vibration produce a lot of small particle of liquid. The linear mean diameter of the mist was about 5 μm. The atomizing rate was 170μl/min at 2.3 W input power.

Keywords: surface acoustic wave, ultrasonic atomizer, nebulizer

INTRODUCTION

Atomization of liquid causes an increase of surface area. For applications such as vapor production, drying, burning, chemical reactions and others, the reaction speed is accelerated by this effect. Although there are several ways to achieve atomization, the ultrasonic atomization technique has been investigated and widely used, especially for rather compact equipment. A merit of ultrasonic atomizers is based on the high energy density and good energy-conversion efficiency of piezoelectric materials.

We propose a surface acoustic wave (SAW) atomizer for miniaturization of ultrasonic atomizers and functional system construction. Actually, ultrasonic atomizers are rather smaller than those produced by other methods, so nebulizers that are handy to carry utilize ultrasonic vibration. However, they are too large for a pocket size nebulizer or direct insertion into internal organs.

We succeeded in operation of the atomizer at five times higher frequency of 48 MHz than previous report[1]. The high frequency operation produced miniaturization, fine mist and high efficiency.

PRINCIPLE OF ATOMIZER

A fabricated surface acoustic wave atomizer is shown in Fig. 1. The atomizer consists of only a vibrator which has an interdigital transducer (IDT). The dimensions of the transducer was 8 mm x 4 mm x 0.6 mm as illustrated in Fig. 2. The vibrator material was 127.8° Y-cut LiNbO$_3$ to generate the Rayleigh wave, a kind of surface acoustic wave. The surface acoustic wave was generated by the interdigital transducer with 20 pairs of electrodes, which was supplied with RF power amplifier. The dimensions of
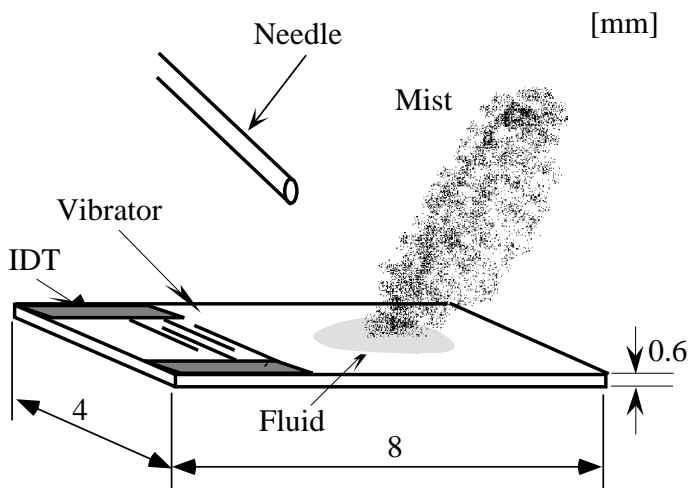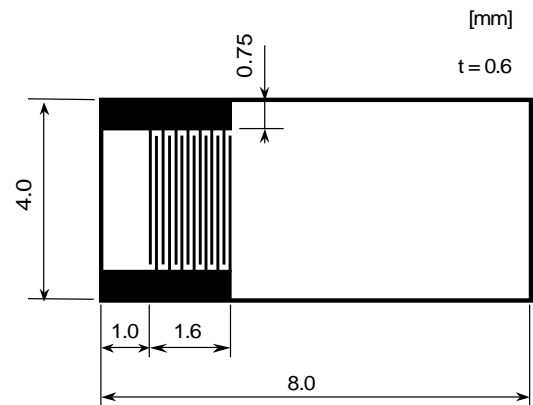

Figure 1: Surface acoustic wave atomizer.

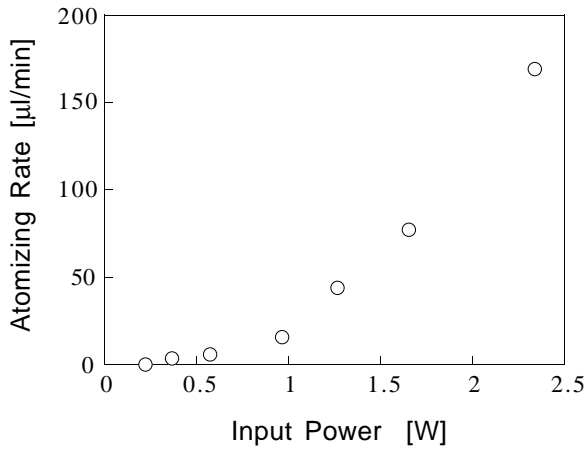| IDT Data			
		pitch	80 μm
material	alminium		20 pairs
strip width	20 μm	aperture	2.4 mm

Figure 2: Dimensions of the SAW device of 48 MHz.

Figure 3: Atomizing rate of the 48 MHz SAW device.

the IDT were 80 µm electrode pitch, 20 µm electrode strip width and 2.4 mm aperture. Since the Rayleigh wave length was about 80 µm, decided from the electrodes pitch, the driving frequency was about 48 MHz

The atomizing mechanism is not vapor but spray from crests of the surface wave in a fluid. The surface wave is called capillary wave. The capillary wave is generated by the radiation of acoustic wave from the SAW device surface. When the liquid layer on the SAW device was half mm or less, the capillary wave was generated strongly enough for atomization.

DRIVING POWER

We used tap water for experiments of the 48 MHz atomizer. The water was supplied by dropping a droplet which was made on a needlepoint of a syringe. Intermittent drive at 1 ms interval and 10% driving period was used to operate at high vibration amplitude with low mean power
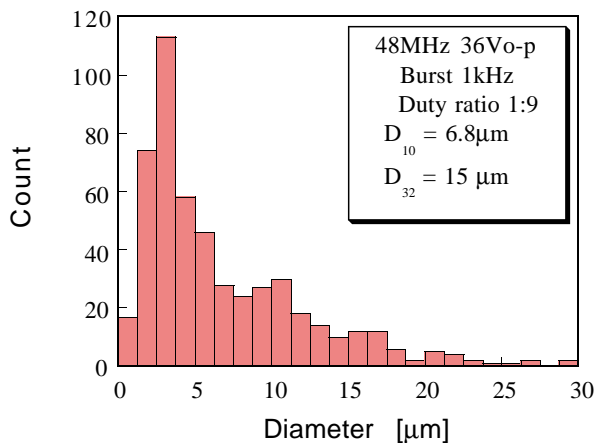

Figure 4: Particle size distribution of 48 MHz device.

input. With this operation, we could prevent a transducer from being damaged by heat.

The atomizing rate versus the driving power is shown in Fig. 3. If the driving power was smaller than 0.2 W, a mist was not generated. The atomizing rate increased leniently against the driving power from 0.4 W to 1.0 W. At high vibrating level, more than 1.0 W of the driving power, the atomizing rate increased rapidly. The maximum atomizing rate was about 170 µl/min at 2.3W input power. The atomizing rate of the small atomizer was little higher than that of a previous 9.6 MHz transducer[1].

PARTICLE SIZE

To measure the particle size distribution, water was colored by adding a little black ink. Then we trapped droplets sprayed by the 48 MHz transducer in a lubricating oil and took photographs of the droplets with a microscope. The droplets on the photographs were counted using an image processing software.

The particle-size distribution at the driving voltage of 36 Vo-p is shown in Figure 4. The distribution has two peaks. The first peak was at about 3 µm. These droplets were atomized from the crests of capillary wave of 48 MHz. The second peak was at about 11 µm. This peak was due to the intermittent burst drive.

The mean diameter versus the driving voltage is shown in Figure 5. At the driving voltage of 36 Vo-p, the linear mean diameter was 6.8 µm and the Sauter's mean diameter was 15 µm. Both the linear and the Sauter's mean diameters decreased with increase of the driving voltage. The mean diameters at 50 Vo-p were about 65 % of those at 36 Vo-p, respectively.
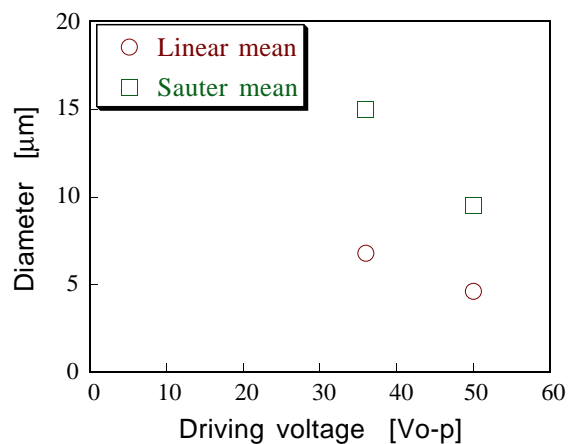

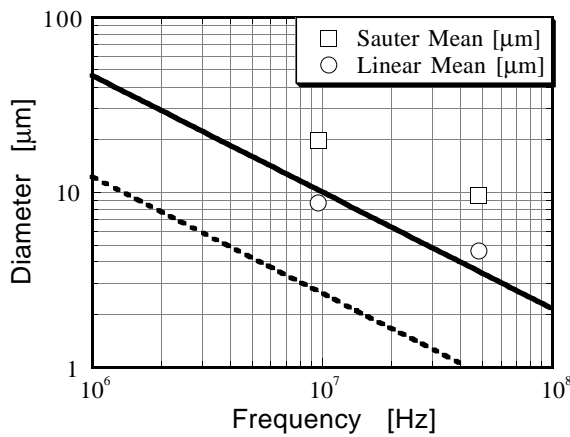*Figure 5: Mean diameter dependence on driving voltage.*

Figure 6: Mean diameter dependence on driving frequency.

Figure 7: Atomizing rate of three kinds of liquid.

The linear mean diameter can be written in the form[2]

$$\overline{d} = \kappa \cdot \lambda = \kappa \left\{ \frac{8\pi\sigma}{\rho f^2} \right\}^{\frac{1}{3}}$$

where $\overline{d}$ is the mean diameter, κ is a proportional constant, σ is the surface tension, ρ is the liquid density and f is the exciting frequency. In a frequency range below 1 MHz, The proportional constant κ is less than 1.0 from previous researches. But in these investigations, the vibration intensities were maintained at rather low level to suppress generation of larger particles. Actually, the particle size depends also on the vibration intensity. Usually, the particle size become large at high intensity vibration level[2].

The mean diameters versus the driving frequency is shown in Fig. 6 from this investigation. The straight lines in the figure shows $d \propto f^{-\frac{2}{3}}$. The solid line means κ =3.8 and the dotted line means κ =1.0. The value of κ was rather large in our experiments. Maybe this is because the vibration levels were high when we measure the particle size. Anyway, the produced mist is very fine, so that the mist is something like dry fog.

EFFICIENCY

Energy required for atomization is calculated from the next equation[3].

$$W = \sigma N \times 4\pi r^2 = \sigma \frac{V}{4/3\pi r^3} \times 4\pi r^2 = \frac{3\sigma V}{r}$$

where W is energy, V is amount of atomized liquid, r is the radius of the droplets, N is number of the droplets and σ is surface tension of the liquid. At the operation frequency of 9.6 MHz, atomizing quantity of the atomizer was 0.58 ml per minute when the input power was 9.3 W. From the surface tension of water of 7.3 x 10^{-2} J/m^2 and the mean diameter of 10.6 µm, the atomization efficiency was 0.0043%. This value is one-third of a handy type ultrasonic nebulizer on the market[4]. In the case of the 48 MHz device, the efficiency was improved up to 0.012 %. This efficiency is almost same as that of the nebulizer on the market. The driving power, the atomization rate and others are summarized in Table 1.

We tried ethanol, water and olive oil to know the influence of viscosity. Atomizing rate of ethanol was about 9 times as much as that of water at the driving voltage 100 V$_{o-p}$ as shown in Fig. 7. The olive oil was not atomized from capillary wave at driving voltage of 75 V$_{o-p}$ or more. At the temperature of 25˚C, viscosity of water and ethanol are 0.9 cP and 1.1 cP as listed in Table 2. On the contrary, viscosity of olive oil is large value of about 80 cP. To atomize liquid from capillary wave, viscosity must be small

Table 1: Performances of the ultrasonic atomizers.

	Input power	Atomizing rate	Atomization energy	Efficiency
9.6 MHz atomizer	9.3 W	0.58 ml/min	0.40 mW	0.0043 %
48 MHz atomizer	2.3 W	0.17 ml/min	0.28 mW	0.012 %
Nebulizer on the market	1.2 W	0.25 ml/min	0.18 mW	0.015 %

and there may be limit value for atomization. Although water and ethanol have similar value of viscosity, ethanol was atomized much more than water. This is because ethanol spreads thinner so as to generate capillary wave easier and the small liquid surface tension requires less energy for atomization.

Table 2: Characteristics of the liquids.

		ethanol	water	olive oil
Viscosity	(25°C) [cP]	1.1	0.9	80
Surface tension	(20°C) [mN/m]	22.3	72.8	32

CONCLUSION

This atomizing element requires only electrodes and low profile. So this construction of the atomizer has advantage of miniaturization. If we apply 100 MHz, the dimensions of the device would become smaller. Such a small atomizer will be useful for medical applications. For example, a liquid medicine can be sprayed to the diseased target directly with the atomizer on an endoscope as shown in Fig. 8. The miniaturized atomizer will be effective to control the atmospheric conditions for chemical process.

REFERENCES

[1] M. Kurosawa, T. Watanabe, A. Futami and T. Higuchi, "Surface acoustic wave atomizer," *Sensors and Actuators*, A, 50 pp.69-74, 1995.

[2] R. J. Lang, "Ultrasonic atomization of liquid," *J. Acoust. Soc. Am.*, vol.34, pp.6-8, 1962.

[3] A. Giovannini, D. Guyomar, M. Gschwind and G. Fonzes, "Evaluation and design of new piezoelectrical droplets generator," *IEEE Ultrasonics Symp.*, Cannes, pp.611-614, 1994.
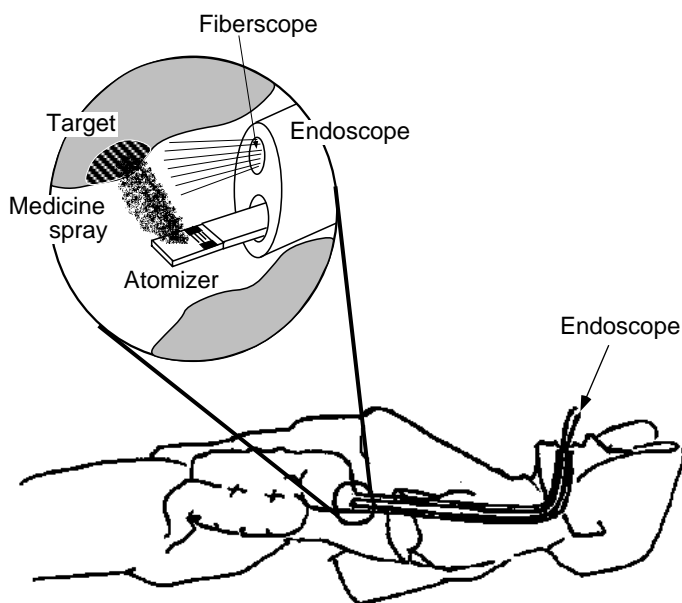
[4] OMRON ultrasonic nebulizer, NE-U03, Instruction manual.

Figure 8: Medical application of SAW atomizer.