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Droplets merging through wireless ultrasonic actuation

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ABSTRACT

A new technique of droplets merging through wireless ultrasonic actuation has been proposed and experimentally investigated in this work. The proposed method is based on the principle of resonant inductive coupling and piezoelectric resonance. When a mechanical vibration is excited in a piezoelectric plate, the ultrasonic vibration transmitted to the droplets placed on its surface and induces merging. It has been observed that the merging rate of water droplets depends on the operating frequency, mechanical vibration of piezoelectric plate, separation distance between the droplets, and volume of droplets. The investigated technique of droplets merging through piezoelectric actuation is quite useful for microfluidics, chemical and biomedical engineering applications.

1. Introduction

Droplets merging have the potential applications in the microreactors [1–5], nanoparticle synthesis [6–7], cell encapsulations [8–9], and protein crystallization [10]. It has been observed that typically in a microfluidic device, two droplets are merged due to their differences in speed moving along the channels. The droplets utilize their size and viscosity difference [11], pillar structure [12], fusion chamber [13], and surface properties [14] to induce the difference in speed of droplets. Droplets are also merged in an electric field by utilizing charges of opposite sign on two different droplets, thus overcoming the stabilized forces caused by surface tension and lubrication [15,16]. Similarly droplets can be merged by transmitting ultrasonic vibration to the droplets dispensed onto the surface of a piezoelectric component. So far there has been no such scheme reported for droplets merging by using ultrasonic actuation. To widen the application range, droplets merging through piezoelectric actuation are investigated in this work. In contrast with the conventional method of merging, the proposed technique has the following advantages. There is no need to use microchannel for the motion of droplets. Two droplets with the same size and viscosity can be merged successfully. The droplets can be dispensed on to the actuating surface simultaneously or at different time. The proposed device has simpler structure and the potential to be smaller than the conventional devices for droplets merging. It is also more flexible in the size and physical properties of droplets to merge. The investigated wireless technique is quite useful and essential for real-life applications where the direct wire connection is not possible and also not convenient to drive directly the piezoelectric devices used for fluid manipulation in a microsystem.

2. Experimental setup, operating conditions and mechanism

The experimental setup for the merging of microdroplets by a wirelessly powered piezoelectric component operating in the thickness vibration mode is shown in Fig. 1. The piezoelectric component is energized through resonance based wireless energy transfer system. The wireless system comprises of an input A.C. power source, transmitting coil, receiving coil, and resonant capacitor. The input A.C. source (used a function generator TG 550 and an amplifier HSA 4101) is supplied to the transmitting coil. The receiving coil is placed coaxially away from the transmitting coil over a relatively far distance. The piezoelectric component is connected across the receiving coil. One external capacitor is used to make the transmitting coil resonant having the capacitance close to the clamped capacitance of the piezoelectric component operating in the thickness mode. The transmitting coil gets excited at its resonant frequency and generates alternating magnetic field. The transmitting and receiving coils are magnetically coupled with each other. The receiving coil captures the generated magnetic field from the transmitting coil and that received energy is delivered to the piezoelectric component. The driving frequency is close to the transmitting and receiving coil's resonant frequency and mechanical resonant frequency of the piezoelectric component operating in the thickness vibration mode. The configuration of the wirelessly powered piezoelectric component operating in the thickness vibration mode is

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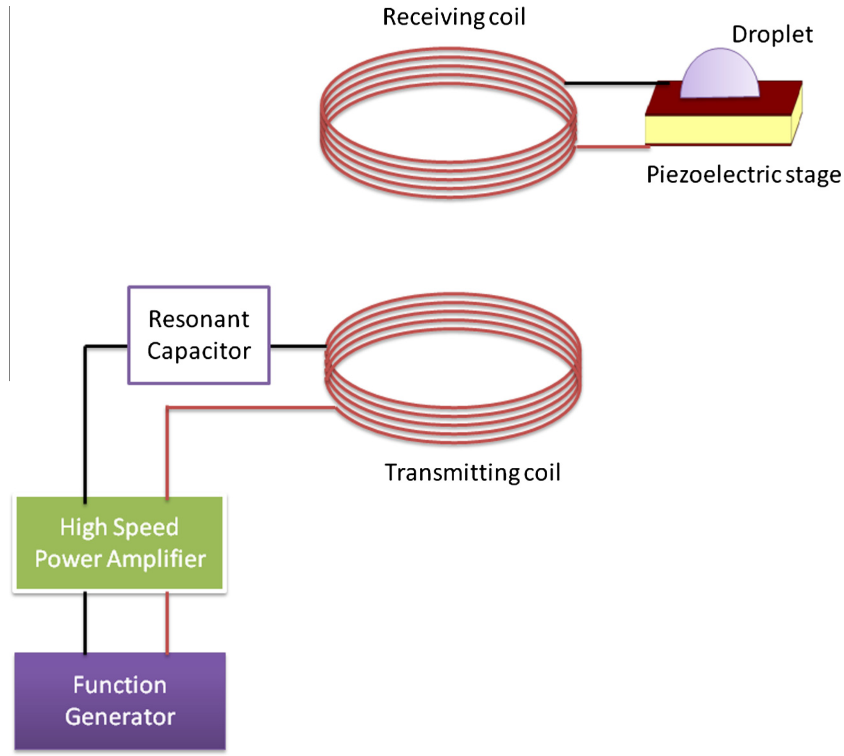

Fig. 1. Experimental setup for the merging of microdroplets by a wirelessly powered piezoelectric component operating in the thickness vibration mode.

shown schematically in Fig. 2(a) and its photograph is depicted in Fig. 2(b). The piezoelectric plate is made of lead zirconate titanate (PZT) ceramic material (supplied by Fuji Ceramic C-203). It is poled along its thickness direction. The component has silver electrode on its top and bottom surfaces. The component has piezoelectric charge constant (d_{33}) 325 × 10^{-12} m/V, mechanical quality factor (Q) 2000, dissipation factor (tanδ) 0.3, and relative dielectric constant ($\varepsilon_{33}^{T}/\varepsilon_0$) 1450. Compared with the single crystal and perovskite piezoelectric materials, the lead zirconate titante (PZT) also has the high piezoelectric constants and high mechanical quality factor. The PZT also has a larger electromechanical coupling factor (k_{33}) than others. Thus, C-203 PZT is chosen as the original material for the experiment and analysis. From the frequency constant of the piezoelectric material (N_t = 1450) and impedance characteristic (measured by an impedance analyzer HP4194A) as depicted in Fig. 3, it is found that the resonance frequency of the piezoelectric plate in the thickness vibration mode is 776 kHz.

The experimental studies are performed under the following conditions. The dimension of the piezoelectric component used in the experiments is 8 × 4 × 2 mm^3. It operates in the thickness vibration mode. The transmitting and receiving coils are wound with copper wire to form helical coils of 6 cm outer diameter.

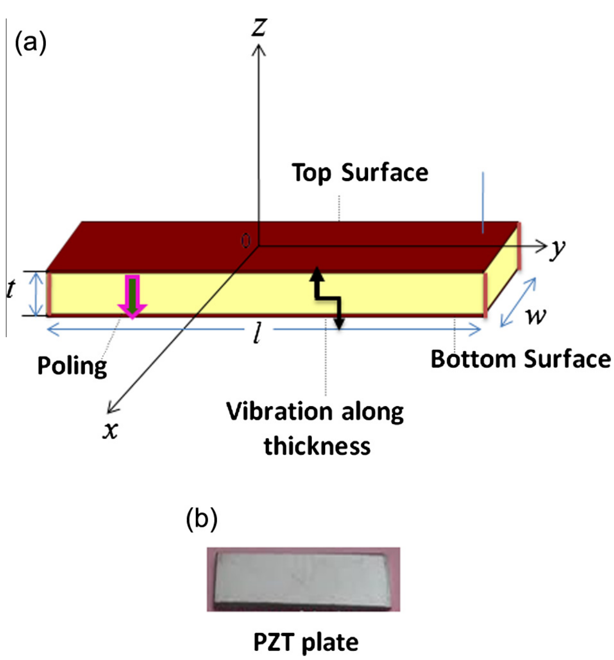

Fig. 2. Configuration of the piezoelectric component operating in the thickness vibration mode (a) Schematic diagram. (b) Photograph of PZT (Lead Zirconante Titanate) plate.

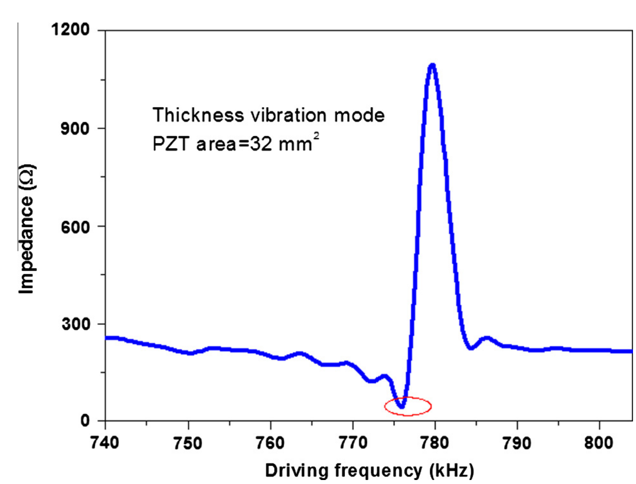

Fig. 3. Measured impedance characteristics of the driven piezoelectric component.