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Original Article

To Develop Piezoelectric based Acoustic Microfluidic Mixer

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Abstract: The main of this research is to solve the problems of the mixing of fluids in microchannels. The aim is to improve the mixing efficiency of the microchannel by employing the piezoelectric actuator. The objectives of the project are to, producing ZnO (Zinc Oxide) thin films, preparing the microchannel with desired dimensions and examining the mixing efficiency of the microchannel by employing the piezoelectric actuator. The ZnO nanoparticles were produced by the coprecipitation method, and the purity and phase were checked by using the XRD method, the ZnO thin films were produced by the Ultrasonic Spray pyrolysis, the thickness of the thin films was determined by using the Eddy current method, the mixing efficiency was measured by powering the piezoelectric actuator by AC source. The size of the nanoparticles is 53.88 nm, The thickness of the ZnO-coated copper thin films is 102 μm, the mixing efficiency can be increased up to 93.47% with the help of an active source of energy Piezoelectric actuator. The mixing efficiency is further increased by increasing the length of the microchannel, increasing the cross-sectional area of the microchannel, in the maximum voltage kept at 5 V because of the limitation of the piezoelectric actuator.

Keywords: Microfluidic Mixer, Piezoelectric Actuator, Piezoelectric Effect, ZnO nanoparticles, ZnO thin-films.

1. Introduction

The flow in microchannels is laminar (i.e., layered). There is no convection on the streamline flow that is why the fluids mix very slowly, only by diffusion. Therefore, they need an actuator for the proper mixing of fluids. In recent years, Zinc Oxide (ZnO) nanostructures (Nanorods/nanowires) have become

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potential materials for various sensor development because of their unique structural, semi-conducting, and piezoelectric properties. ZnO not only exhibits both semiconducting and piezoelectric properties but also biocompatible and environmentally friendly. As per the recent studies, the wurtzite ZnO material exhibits excellent piezoelectric properties alongside the [0001]-direction because of the non-centrosymmetric structure. As a typical II-VI wide bandgap compound, it has been long studied as a piezoelectric material. A non-centrosymmetric material does not have points of inversion symmetry throughout its volume. Not all non-centrosymmetric are piezoelectric, however, the exception is materials with class 432. Hence, the potential applications include Micro/Biosensors, Piezoelectric Nano-generators, Light Emitting Diodes, emission devices, and Solar cells. However, a very little amount of literature exists about the usage of ZnO thin films as Fluid mixers. The Piezoelectric-based Acoustic Microfluidic mixer makes use of materials that emit Surface Acoustic Waves (SAW) which are low-frequency vibrations when powered by a voltage source, this is an inverse process of the Piezoelectric effect where Piezoelectric material produces potential difference across a circuit upon stressed by an external force. Other advantages of ZnO thin films for SAW devices include easy integration with microsensors and actuators on a similar substrate, excellent bonding with various substrate materials, high-temperature stability, and low-cost deposition. In this research work, the Piezoelectric-based Acoustic Microfluidic mixer was fabricated by using the ultrasonic spray Pyrolysis process and examine the mixing efficiency of the Y-microchannel made up of PMMA material and the maximum mixing efficiency was determined.

2. Experiment

The ZnO nanoparticles were prepared by using the Coprecipitation method, Coprecipitation (CPT) is that carrying down by a precipitate of substances normally under the conditions employed.

2.1. Preparation of ZnO Nanoparticles

Zinc acetate dihydrate ($Zn(CH_3CO_2)_2.2H_2O$) and Sodium Hydroxide (NaOH) were dissolved in deionized water to form two transparent solutions with 0.5 M and 1 M concentrations respectively. Then using two pipettes poured these solutions into a beaker at room temperature. The mixture was stirred for 2 hours during which a white precipitate was formed in the solution. Then the obtained precipitation was separated by centrifugation for 15 minutes at 700 RPM. The ZnO nanoparticles were obtained by washing with deionized water and Acetone and drying at 75 ºC for 6 hours. The Ultrasonic Spray Pyrolysis method was used to coat the Piezoelectric coating (ZnO) on the copper substrate. The Substrate used is Copper cladding polymer with films with a thickness of 35 µm.

2.2. Coating of ZnO on Copper Substrate

1 M of Zinc acetate $Zn(CH_3CO_2)_2$ was dissolved in 100 ml spray solution of 80% Ethanol, 10% HCl, and Ethylene Glycol. The solution was stirred for up to 1 hour using a magnetic stirrer. The heating bed was heated up to 150 and the substrate was separated from the plate by a glass slide. The distance between the bed and the nozzle is 30 cm (Fixed). The flow rate was kept constant at 1ml/min. The spraying was done for five attempts; each attempt duration was one minute separated by a gap of 30 seconds for drying. Annealing was done on a hot plate with 100 ºC for 10 minutes to improve crystallinity. The phase and purity of the ZnO nanoparticles were examined by Powder X-Ray diffraction and the thickness of the ZnO coating of Copper substrates was determined by the usage of the Eddy Current method.

2.3. Preliminary Testing

With the help of a function generator, an alternating potential difference having a sine waveform was applied to one of the developed piezoelectric actuators. The function generator varied the frequency of the potential difference. The piezoelectric actuator at the other end was connected to an oscilloscope. The reading at the output end was used to determine the resonance frequency of the piezoelectric actuator. The natural frequency was determined where the amplitude of output voltage was found maximum during the testing.

2.4. Determining the Mixing Efficiency

The experimental setup mainly consists of the Syringe pump with Water (Fluid-1) and Glycerin (Fluid-2) filled, which supplies the Y-microchannel where the fluids were meant to mix. The Y-Microchannel is made up of PMMA (Poly Methyl Acrylate or Plexiglass) and connected to a syringe pump via a rubber hose. The Piezoelectric actuator was placed at the junction of the Y-Microchannel and connected to a Function generator, which acts as a voltage source for the actuator. For the first attempt, the Voltage is set to 0 V and the mixing efficiency is determined. Then the voltage was increased to 1 V for the second attempt and the second reading mixing efficiency was determined. Then the voltage is incremented by 0.5 V and the respective Mixing Efficiency reading was determined up to 5 V.

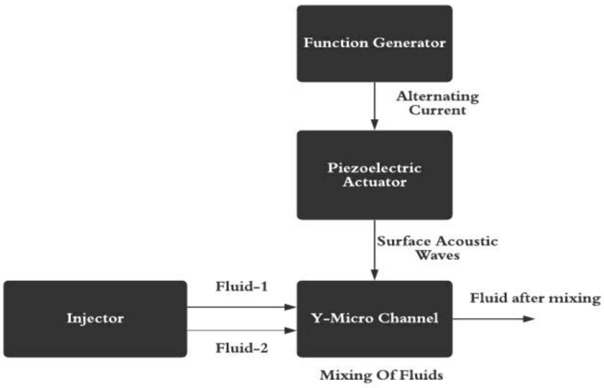

Figure 1. Block diagram of the experimental setup.

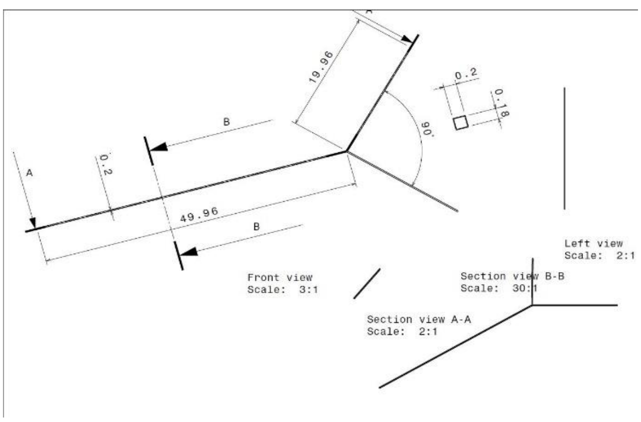

Figure 2. The Y-Microchannel design and dimensions.

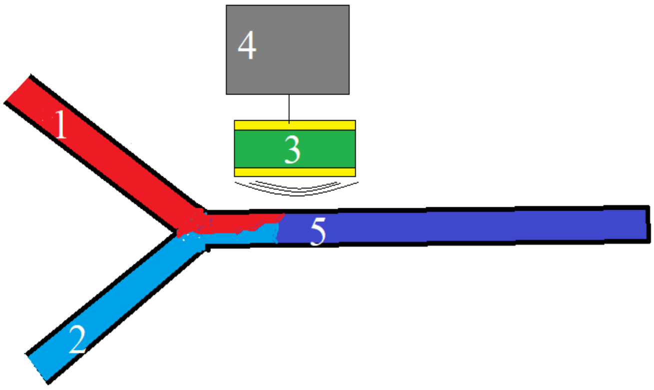

Figure 3. Schematic diagram of mixing of fluids in Microchannel by Surface Acoustic Waves.

Table 1. Description of the schematic diagram of the mixing of fluids in Microchannel by Surface Acoustic Waves

S.NO	Components
1	Fluid-1 (Water)
2	Fluid-2 (Glycerine)
3	Piezoelectric Actuator
4	Voltage source
5	Fluid after mixing

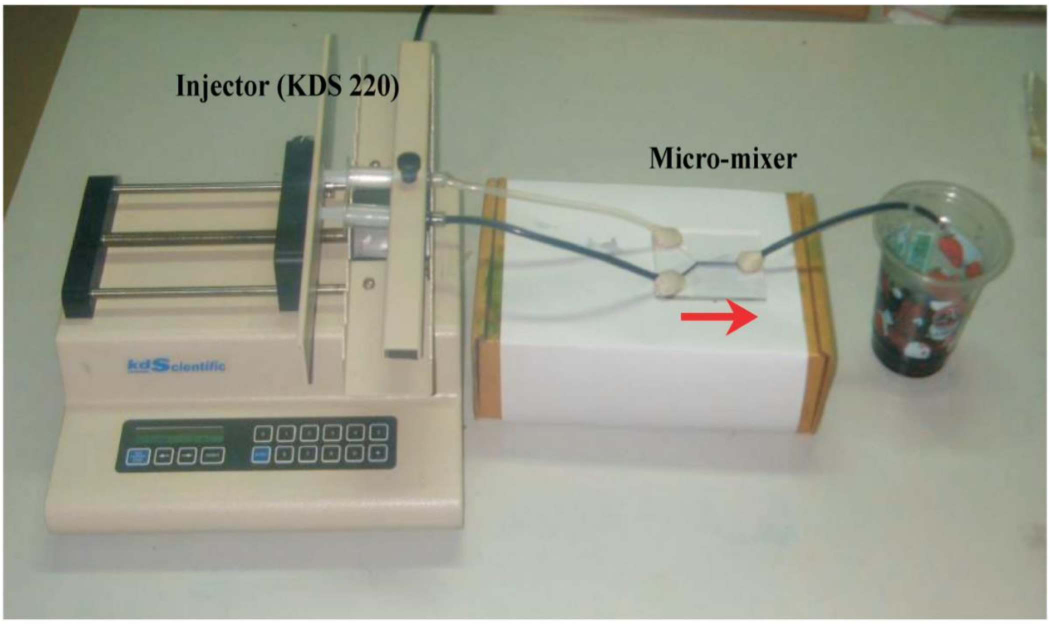

Figure 4. Experimental setup.

3. Results and Discussion

3.1. Characterization of ZnO Nanoparticles

The structural properties of ZnO nanoparticles were obtained by Powder X-Ray diffraction. The XRD pattern of ZnO nanoparticles is shown in Figure 5. The peaks that were obtained correspond to the pure hexagonal wurtzite phase of ZnO with lattice parameters a = b = 3.24982 A° and c = 5.20661 A° (JCPDS no. 36-1451). Reference ZnO peak positions were marked with dotted lines in Fig. There is a small shift in the peak position toward higher angles due to the lower optical band gap of the ZnO Nanoparticles compared to the bulk. This result shows that no other phases of ZnO or impurities have been observed. The crystalline size of the nanoparticles was found to be 18 nm calculated using the Scherrer formula.

$$D = \frac{k\lambda}{\beta \cos\theta} \quad (1)$$

where D is the crystalline size of ZnO, λ is the X-ray wavelength, θ is the Bragg diffraction angle, and β is the full-width at the half maximum of the diffraction peak corresponding to plane (101), and k is Scherrer constant which is 0.9 [..].

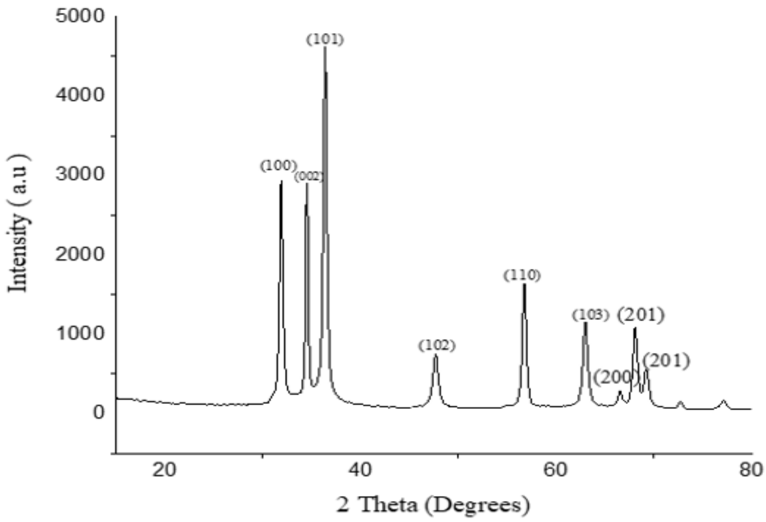

Figure 5. XRD Pattern of ZnO nanoparticles.

3.2. Measuring the ZnO Coating Thickness of ZnO thin Films

The coating thickness can be measured with the help of the Eddy current test. Eddy current testing consists of a probe i.e., a coil of wire made of conducting material with an alternating current. The wire coil creates an alternating magnetic field around itself. The magnetic oscillates at the same frequency as the current running through the coil. When the coil comes into contact with a conductive material, currents opposed to the ones in the coil are induced in the material which is eddy currents. Changes in metal thickness or defects like near-surface cracking will interrupt or alter the amplitude and pattern of the eddy current and the resulting magnetic field. This in turn affects the movement of electrons in the coil by varying the electrical impedance of the coil. The eddy current instrument plots changes in the impedance amplitude and phase angle. The Instrument is calibrated with the help of a calibration membrane and with the probe, the coating thickness can be determined.

Table 2. Reading to calibrate the device

	x (mm)	y
Only substrate	0	5
With standard sheet	0.3	4.5

So;

$$(x - 0)/(0.3 - 0) = (y - 5)/(4.5 - 5) \quad (2)$$

$$y = -\left(\frac{0.5}{0.3}\right) x + 5 \quad (3)$$

For the coated substrate; y= 4.83

Therefore, by the above equation, the coating thickness is found out to be 0.102 mm = 102 micron

3.3. Characterization of ZnO Nanoparticles

The natural frequency of the Piezoelectric actuator was found out by using:

$$f = \left(\frac{k}{2t}\right)\sqrt{\frac{Y}{\rho}} \quad (4)$$

Here ‘f’ represents the natural frequency of the actuator, ‘t’ represents the thickness of the piezoelectric coating; ‘Y’ represents Young's modulus; ‘ρ’ represents the density and ‘k’ is an integer which gives the number of harmonics.

The values of the variables in the natural frequency according the properties of ZnO (101) [Wurtzite]

Y = 111.2 GPa

ρ = 5.1 g/cc

t = 102 micron

Table 3. The natural frequency of the actuator for different harmonics

k	f (MHz)
1	22.8895439
2	45.7790877
3	68.6686316
4	91.5581755
5	114.4477190

3.4. Preliminary Testing (Practical Method for Finding Natural Frequency)

Table 4. Preliminary test results

S.NO	Input Frequency (MHz)	Output Voltage (V)
1	66	3.76
2	67	3.84
3	67.5	3.93
4	68	4.07

5	68.5	4.58
6	69	4.37
7	69.5	4.02
8	70	3.91
9	71	3.85

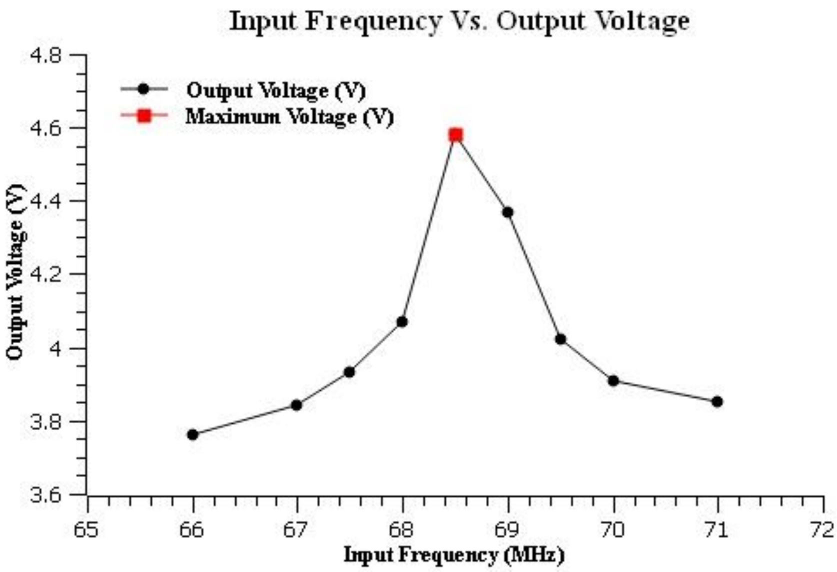

Figure 6. Input Frequency vs. Output Voltage.

The maximum amplitude of output voltage was observed at 68.5 MHz. So the final test was done by applying 68.5 MHz alternating potential difference.

3.5. Determining Mixing Efficiecny

Table 5. Mixing efficiencies at various Input Voltages

S.NO	Input Voltage (V)	Maximum efficiency (%)
1	0.0	9.956
2	1.0	40.345
3	1.5	60.073
4	2.0	72.250
5	2.5	82.905
6	3.0	88.294
7	3.5	90.471
8	4.0	92.028
9	4.5	93.027
10	5.0	93.469

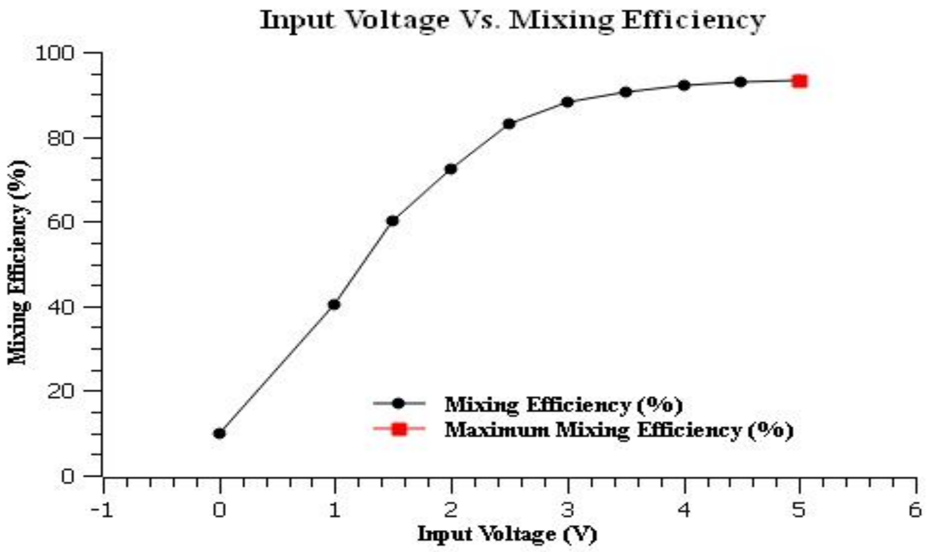

Figure 7. Input Voltage vs. Mixing Efficiency.

The maximum Mixing Efficiency was found to be 93.469% at 5 V Input Voltage.

4. Conclusion

The ZnO nanoparticles produced by the coprecipitation method don't have any impurities or different phases. The ZnO nanoparticles size was found to be 53.88 nm The Coating Thickness of ZnO nanoparticles on the copper substrate was found to be 102 µm. Higher mixing efficiencies can be obtained by using an external source of energy. In this project energy is Surface Acoustic waves which are produced by the Piezoelectric actuator which is powered by a voltage source, Function generator is the Voltage source in this case. The maximum Mixing efficiency was increased to 93.47%.

The Mixing efficiency is further increased:

- Increasing the length of the Microchannel.
- Increasing the Crossectional area of Microchannel.
- Increasing the applied voltage to the piezoelectric transducer.
- In this study maximum voltage was kept at 5 V because of the limitation of the piezoelectric actuator.

The Mixing efficiency can be further increased by using an active or passive-microchannel with different sources of energy.

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