# Underwater Sensing Characteristics of a ZnO Thin Film Sensor Prepared by Spray Pyrolysis

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***In this work, ZnO thin films were prepared by spray pyrolysis technique to fabricate underwater sensors. Results explained that the preparation conditions affect the sensing characteristics and the attenuation in the underwater environment is dependent of distance from sensing signal source and its frequency. The prepared sensor was tested in a water environment containing crude oil and it exhibited reasonable results to sense the oil amount.***

***Keywords***: Thin film sensors, Zinc oxide films, Underwater sensing
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## 1. Introduction

There are many applications of ferroelectric materials, including the measurement of object distance underwater. For underwater techniques, ultrasonic acoustic sensors have better characteristics than do optical devices. Since ultrasonic waves can transmit the through all materials thought not in a vacuum, they are the best choose for application in the detection of opaque objects, underwater image techniques, and in non-destructive measurement. The measurement technique is easy to perform, and the measurement results are accurate. However, using the same sensors to measure distance underwater, the error in distance measurement is seriously enhanced. In order to measure distances accurately, the operating frequency must be increased and the device structure should be improved. Furthermore, to compete with commercial optical cameras in measuring distances, the measuring distance resolution of acoustic devices must be enhanced. The major improvement is made to use high operating frequencies. Devices should be developed for all distance ranges, including long and short distance measurement. On the other hand, a thin film device is a better choice than a bulk piezoelectric ceramic sensor for high frequency acoustic devices. In addition, the thin film acoustic devices fabrication is similar to fabrication process of integrated circuits (IC) process, which will be reduce the fabrication cost of these devices [1]. There are different techniques have been adopted for the deposition of piezoelectric thin films, which include electron beam evaporation [2], RF diode sputtering [3-4], ion beam deposition [5-6], RF planar magnetron sputtering [7-9], MOCVD [10-14], ECR [15], laser ablation [16-20], and sol-gel [21-25].

## 2. Experiment

ZnO films were prepared on glass substrates by a homemade spray pyrolysis system. The different molarities of spray solution (0.3, 0.5, 0.6, 0.7)M of zinc chloride ($ZnCl_2.2H_2O$) were dissolved in distilled water and the solution was carried by the compressed air as a carrier gas then fed into a spray nozzle. The flow rate of solution was 10ml/min flows from a 0.5mm-diameter nozzle at a distance of 25cm to the substrate. The substrate temperature was kept constant at (350°C). The single spraying time was (5s) with different number of sprays. Table (1) indicates the molarity and the corresponding film thickness for the prepared samples.

The ultrasonic testing of the prepared ZnO films was carried out using transmitter/receiver underwater set-up containing of a function generator (B&K precision 3020) and an oscilloscope (KENWOOD CS-1021 20MHz). The amplitude of the incident signal was ($18V_{p.p}$) at frequencies ranging within (0.1-100) kHz. The attenuation coefficient ($\alpha$) of the ZnO films was studied as a function of distance underwater at different frequencies using the following relation:

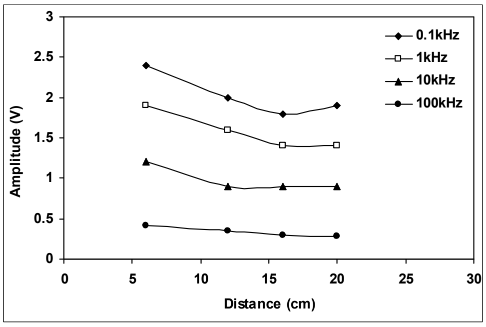
$$A = A_0 \exp(-\alpha d) \quad (1)$$

**Table (1) preparation conditions of the samples prepared in this work**

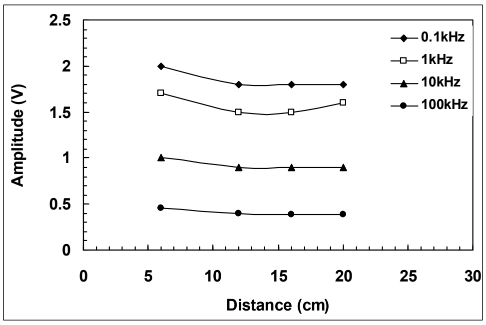
| Sample | Molarity (M) | Film thickness (nm) |
|---|---|---|
| #1 | 0.3 | 765.1 |
| #2 | 0.5 | 939 |
| #3 | 0.6 | 1026 |
| #4 | 0.7 | 1210 |

### 3. Results and Discussion

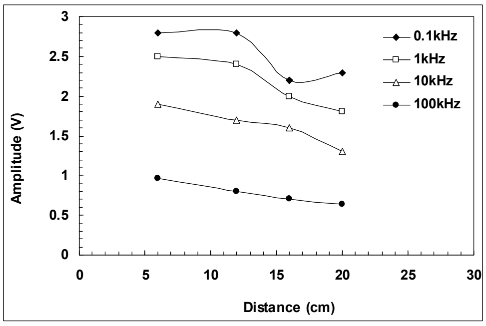
As shown in Fig. (1), the amplitude of the received signal is varied with the distance between the transmitter and the thin film transducer with a 18V incident signal. In general, the amplitude decreases in all samples due to the attenuation inside the testing medium (water) as the volume of water sample is increased as the distance from the source is increased too. So, this effect is in accordance with Beer-Lamberts law of absorption.



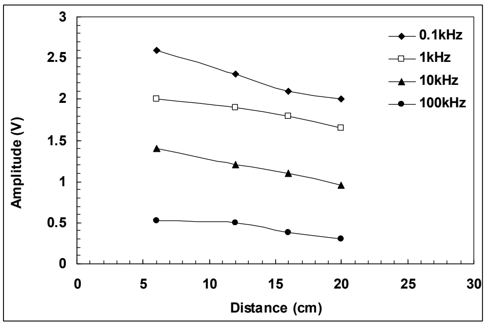

**(a) Sample (#1)**




**(b) Sample (#2)**



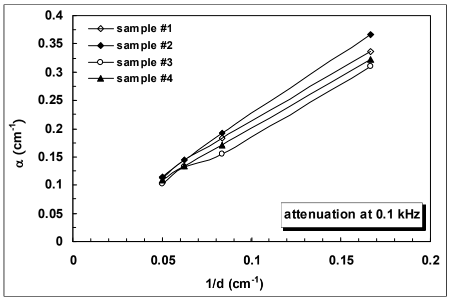

**(c) Sample (#3)**



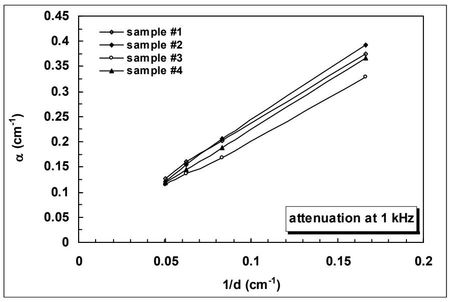

**(d) Sample (#4)**

**Fig. (1) Variation of the underwater received signal with the distance between the transmitter and the thin film transducer at 18V of the incident signal for all samples**

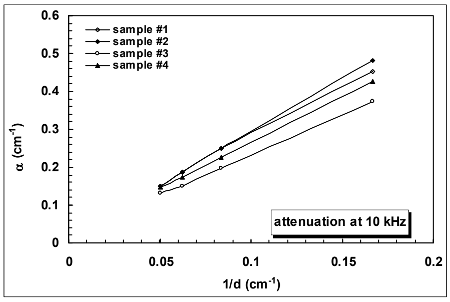
Accordingly, Fig. (2) shows the variation of attenuation ($\alpha d$) by plotting the absorption coefficient ($\alpha$) versus reciprocal of the distance ($1/d$) for all samples at different frequencies shown in Fig. (1). It is clear that the attenuation increases with increasing distance. Sample (#2) explains higher attenuation at low frequencies (0.1, 1 and 10) kHz but at 100 kHz, sample (#1) explains the higher attenuation. Also, sample (#3) explains the lowest attenuation at all frequencies. Therefore, the attenuation characteristics of such sensor are dependent of the transmitted signal frequency.



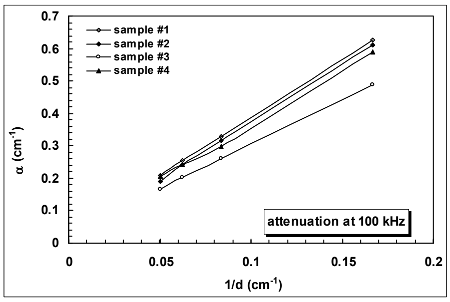

**(a) at 0.1 kHz**




**(b) at 1 kHz**




**(c) at 10 kHz**




**(d) at 100 kHz**

**Fig. (2) Variation of the attenuation coefficient ($\alpha$) with the reciprocal of the distance ($d$) at different frequencies of the incident signal for all samples**

The relation between attenuation and frequency is shown more clearly in Fig. (3). The effect of signal frequency can be interpreted as following. The transmitted signal is attenuated by the transmission medium (water) within a period of time, which is the time required by the signal to reach the sensor point. This transmission makes some turbulence in the transmission medium and such turbulence may remain exist over this period of time. When transmission frequency increases, the transmission medium will contain effects of consecutive signals and constructive and destructive interferences would take place. Accordingly, the thin film sensor would receive transmitted signals at a higher frequency and if the sensor needs longer time to distinguish the received signals from each other, then higher frequency may cause destructive interference at the sensor, which in turn affects the final recorded signal amplitude.

If the application requires using such thin film sensors in small samples with high accuracy, then working at small distances (*d*) and low frequencies is the preferred. However, such sensors can be used in case of large samples if the fine accuracy is not very important. Samples of chemicals, medicines and laboratory fluids can be considered as small samples. As well, crude oil pools in seas and drinking water reservoirs are large ones.

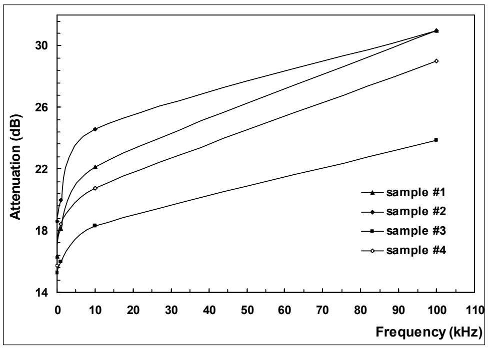



**Fig. (3) Relation between attenuation and frequency for all samples**

The prepared samples were tested in an environment containing 300ml of water with different amounts of crude oil by transmitting a 18V signal at different frequencies (0.1, 1, 10 and 100) kHz in this environment and recording the amplitude of the received signal at a distance of 8cm and the results are shown in Fig. (4). The amplitude of the received signal was increasing with increasing the amount of oil in the water environment. At lower frequency (0.1 kHz), the maximum signal amplitude was recorded (3.7V) and the amplitude was decreasing as the signal frequency was increased. This is one of the most common applications of the thin film sensors as the sensitivity of such sensors can be optimized by the preparation conditions.

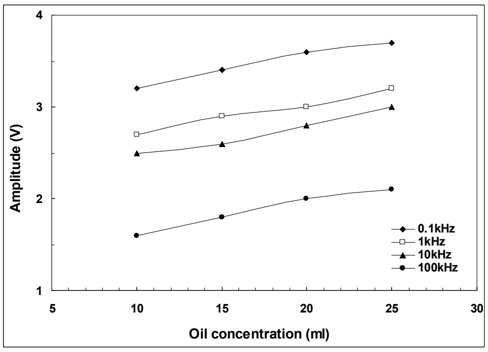



**Fig. (4) The sensing characteristics of a 300ml solution of water and crude oil using sample (#3) with a 18V incident signal at distance of 8cm**

## 4. Conclusions

The obtained results explained that the preparation conditions affect the sensing characteristics as the higher molarity used for preparing thin films does not necessarily give the best results. Also, the frequency of the transmitted sensing signal is an important parameter in such method and using low frequencies presented the best results. The attenuation in the underwater environment is dependent of distance from sensing signal source and its frequency. The prepared sensor exhibits reasonable sensing characteristics in a water environment containing crude oil and this would be encourage optimizing the sensor characteristics more in order to improve them in such field of applications.

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