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Piezo Spirometer: A New Device for the Diagnosis of Pulmonary Failure

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Abstract

This study offers a cheap and rapid method for the measuring of breath or measuring the size and capacity of the lung. In this innovative method, the respiration flowmeter than other conventional methods with high costs will be done very fast and accurate. In this device, the measurement accuracy and speed will increase dramatically, because of the high-frequency response than other methods. In this paper, the results of design and manufacturing the spirometry device using nanotechnology are discussed, which including synthesis of piezoelectric ceramics PMN-PT and the amplifier circuit design.

Keywords: Spirometer; Piezoelectric ceramic; Nano-technology

Introduction

Spirometry is the most common of the Pulmonary Function Tests (PFTs), measuring lung function, specifically the measurement of the volume and speed the flow of air that can be inhaled and exhaled. Spirometry is an important tool used for generating pneumotacho graphs which are helpful in assessing conditions such as asthma, pulmonary fibrosis, and cystic fibrosis. Nowadays, spirometers can measure lung volumes, such as tidal volume, and lung capacities, such as total lung capacity. Figure 1 shows the typical lung volumes. Spirometry is a medical test, the volume of each inhalation and exhalation can be measured as a function of time. Current estimates, as a function of time or the rate at which volume changes can also be measured by spirometry. In addition to measuring the size and capacity of the lung can also speed the withdrawal of gases from the lungs by measuring lung function test can be measured. It measures about opening the airway, airway disorders or whether the patient is small or large airway problem is obtained. Generally, methods of assessment and spirometric volume flowmeter are categorized into volume-meter and flow-meter.

The method that was used in this study is based on the flow-meter one. The flow-meter includes a variety of techniques that some of them are mentioned below. There are different methods for measuring lung volumes such as turbine-type respirometers [1], Fleisch spirometer [2] and hot-wire respiratory [3]. One of the best devices for the air flux measurement, by a certain resistance which is fixed inside the tube, is Fleisch-type spirometer [4]. This spirometer has many disadvantages, such as increasing the resistance because of accumulation of fluids or another pollutant, and dependence of the characteristic viscosity to the air temperature.

The piezoelectric phenomenon was discovered by Pierre Curie and Curie Jackie during the study on the charge effects of crystals such as quartz, and Rachel salt in 1880. They showed the thin sheets of quartz crystals, if at the particular shape can be cut, due to mechanical pressure, they create an electrical potential. The crystals such as quartz will produce positive and negative charges on their surfaces when the pressure applies on both sides. The amount and condition of the electric charges are proportional to the external pressure, and they disappear when the pressure is removed [5]. In 1935, Busch and Scherrer discovered the piezoelectric phenomenon in potassium dihydrogen phosphate (KDP), then the barium titanate (BT), lead zirconate titanate (PZT) and PMN-PT was discovered in 1950, 1995 and 1940 respectively. The piezoelectric and dielectric properties of these compounds are remarkable [6,7]. The piezoelectric spirometer measures the lung volume by using flowmeter method and piezoelectric ceramic. The main types of piezoceramics include PZT and PMN-PT. In this study, the PMN-PT piezoelectric ceramic has been used to measure lung volume. The aim of this project is design and manufacturing the spirometer device using PMN-PT piezoelectric ceramic.

Experimental Method

Preparation of PMN-PT nano ceramics

Usually, the (y)Pb(Mg_xNb_{1-x})O_3-(1-y)$PbTiO_3$ ceramics with 27%< y<38% are prepared by a conventional solid-state reaction method [8]. However, this technique carries some problems such as the inability to control the chemical balance, the elemental composition fluctuations and imperfect fit with the microstructure, because of the high calcination temperature. So to avoid these problems in PMN-PT production, the calcination temperature should be low. The low heating process in the manufacture of ceramic powders leads to the homogeneous structure with a fine mixture of compounds. To improve the piezoelectric coefficients, nanotechnology procedures usually apply. For this purpose, the gel combustion synthesis was used, and the nano-powders of PMN-PT were near morphotropic phase boundary (MPB).

Nano-powder of PMN- PT was synthesized by using metal organic and salt precursors as starting materials. Raw materials used in this experiment consist of lead nitrate [$Pb(NO_3)_2$], magnesium acetate [$(CH3COO)_2Mg.4H_2O$], niobium ammonium oxalate [$NH_4[Nb(C_2O_4)_2(H_2O)].4H_2O$] and titanium isopropoxide $Ti[OCH(CH_3)_2]_4$. An aqueous solution of each single cation (i.e. Pb^{+2}, Ti^{+4}, Nb^{+4} and Mg^{+2}) was prepared by dissolving lead nitrate, zirconium nitrate and magnesium acetate in distilled water. Titanium isopropoxide was dissolved in the mixture of nitric acid, citric acid and hydrogen peroxide for preparation of Ti^{+4}.

A proxo-citrate-niobium complex $(NH_4)[NbO(O_2)(C_6H_4O_7)]$ was prepared from niobium ammonium oxalate, citric acid, nitric acid, and ammonia. The solutions of lead, titanium, niobium, and

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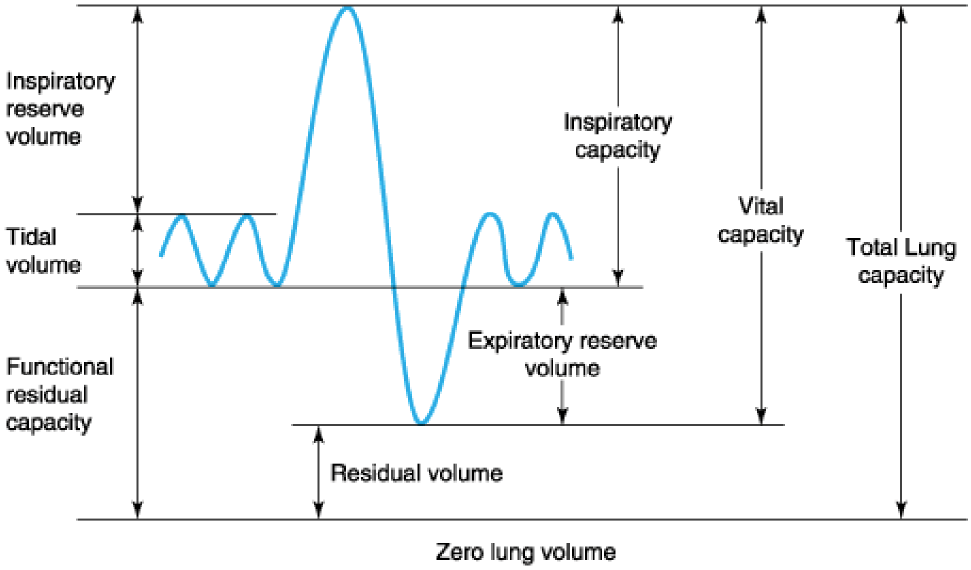

Figure 1: A typical lung volumes.

magnesium were added to the aqueous solution of citric acid under continuous stirring at 60-70°C and finally, at the end, the pH of the sol was maintained at 7 by the addition of ammonium hydroxide. In order to obtain the gel, the peroxo-citrato-nitrate sol of PMN-PT was heated at about 95°C. PMN-PT nano-powders were produced by the citrate-nitrate gel-combustion technique [9-11]. The flow diagram of the nano-powder's processing method employed in this study is shown in Figure 2.

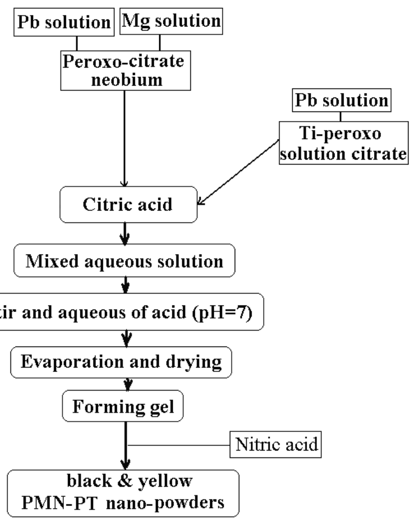

Figure 2: The flow diagram of PMN-PT nano-powders.

Design the piezoelectric spirometer sensor

According to the thickness (2 mm) of PMN-PT ceramics, the various components of spirometer designed and built. The main body of the spirometer was selected from healthy plastic and the shaky mass was formed from steel. These studies were performed to select the best result. The overview of the device is shown in Figure 3.

To better connect the pieces and prevent the transverse vibrations, the spring was used. These springs keep the various components of the piezoelectric ceramic and the trembling together causes the force of the acceleration sensor to be transmitted by the vibrating mass with the least waste. A major component of the sensor of the respiration force is PMN-PT piezoelectric ceramics. According to research, these are the best combination device for the spirometer from the point of sensitivity to forces respiration and having good mechanical strength. The two piezoelectric ring was used to increase the output voltage which the level of positive and negative rings has been connected to the amplifier circuit by the copper electrodes.

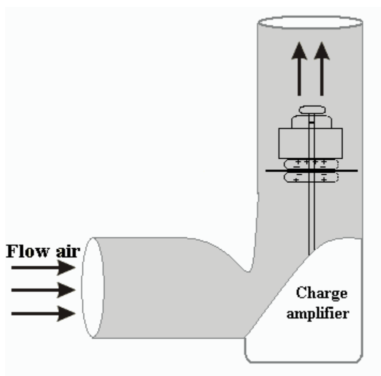

Figure 3: The main body and the shaking mass of the spirometer.

Design of electronic circuit spirometer

To increase the system output for demonstrating on the digital display, the system should be used from electronic circuits amplifiers such as voltage and charge amplifiers. In voltage amplifier, because the sensors are installed in outer space, it is possible to receive noise from the environment. In this study was to use a charge amplifier that has an output proportional. The main charge amplifier circuit is shown in Figure 4.

The piezoelectric piece can be considered as a capacitor with

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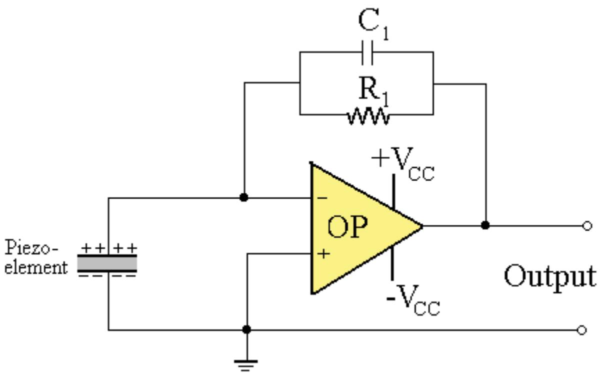

Figure 4: The practical amplifier used in spirometer.

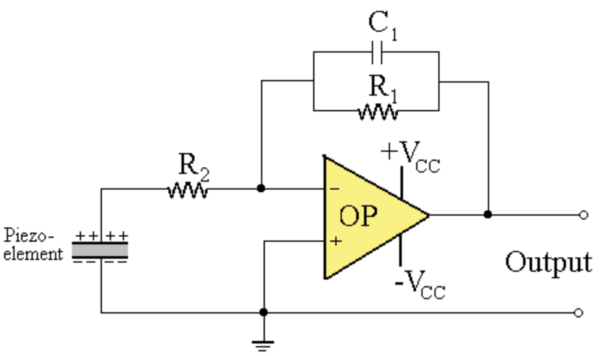

Figure 5: The charge amplifier with high frequency response.

capacitance C_2 and a source voltage V_{g1} in the circuit. The value of the piezoelectric effect capacitor C_2 is approximately 1nF. The exact amount of this capacitor can be determined by measuring each piece. If in this case the capacitor C_1 considered as 1 nF, the gain amplifier will be 1 mV/pC and according to the sensitivity of the pieces are in the range of 1 to 50 pC/g then the amount of capacity C_1, is acceptable. The feedback resistor (R_1) that is in parallel with the capacitor (C_1) is for bias. This resistance effect on the amplifier frequency response. Frequency response of the amplifier at low frequencies is quite predictable, but at frequencies above 1 MHz, which often cause unwanted gain around the resonant frequency of the piezoelectric device. To limit this effect, a resistor can be added to the input circuit like Figure 5. The adding this resistance, improved high frequency response of the circuit.

Results and Discussion

X-ray diffraction patterns of PMN-PT powders (Heating rate: 2°C/min from room temperature to various temperatures ranging from 700°C to 850°C for 2 h) are shown in Figure 6. The presence of a monoclinic phase at temperature of 850°C can be identified from this figure.

The XRD results also reveal the existence of a perovskite-type phase for the gel-combustion method in all temperatures. At temperatures lower than 850°C, the samples still contain some pyrochlore phase while at 850°C disappear completely. The calculated lattice parameters obtained in this work are consistent with the reported values for 0.65 PMN-0.35 PT bulk ceramic [12,13]. The typical TEM image of the PMN-PT powder calcinated at temperatures of 800°C prepared by the gel combustion method is shown in Figure 7. From TEM analysis, the primary particle size of the powders can be determined. The primary particle size of the PMN-PT powder was found to be approximately 25 nm in diameter.

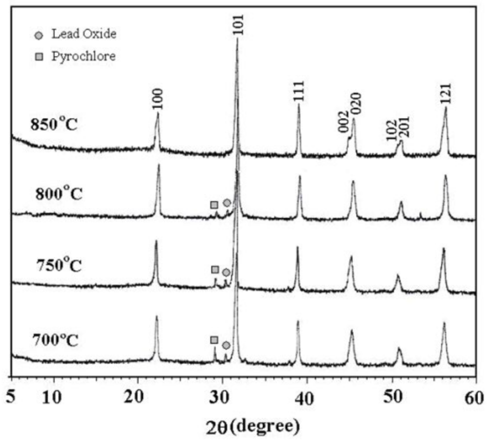

Figure 6: XRD spectra of samples of the PMN-PT calcined at different temperatures.

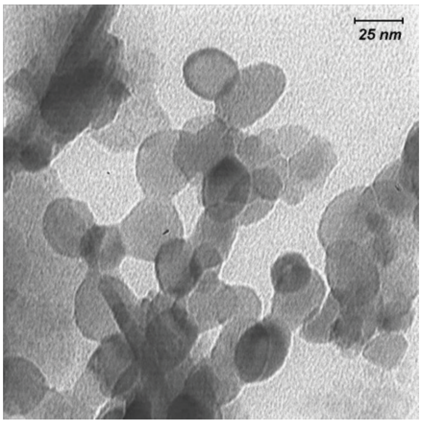

Figure 7: TEM micrograph of the prepared PMN-PT powders at 800°C.

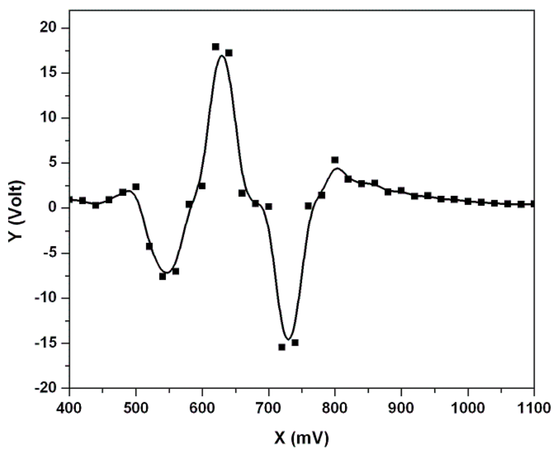

Figure 8: Spirogram showing lung volumes and capacities.

The information analog obtained from the circuit to transmit and analysis data, the analog to digital converter is required. According to the sampling rate, the microcontroller (at mega 10) as A/D can be used. The microcontroller-duty converts the analog signal into digital data, which uses the serial port (RS232) is transmitted to the computer. In order to analyze the data and convert the voltage to the volumetric flow rate, a software is required. Figure 8 shows the results of the piezo spirometry curves correspond Miller and Porszasz [14,15].

Conclusion

We designed a new spirometer using PMN-PT piezoelectric ceramic. It has a high-frequency response (about 16 MHz) and is capable to measure the flow rates of breath accurately. This instrument is expected to be very useful as it is inexpensive, user-friendly and portable. The piezo spirometer has the ability to communicate with a personal computer, namely through a serial port RS232 connection. This facilitates the storage of spirometric data for analysis and records (database), printouts and another application. In the near future, such systems are expected to provide inexpensive medical care to thousands of patients.

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