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Detection of CO_2 Pollutions Based on Phononic Crystals †

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Abstract: Phononic crystals are periodic artificial composite materials are used to control the propagation of elastic and acoustic waves through the entire spectrum of the phonon waves. The defected acoustic band gap materials are a new generation of sensing technology based on layered cavities. Based on the resonance phenomnon and defect peaks that generated in the band gaps, PnCs could provide new and innovative applications conventional materials cannot do. One of these unique applications is the sensor application for many chemical and biomaterials. Therefore, in the proposed project we intend to extend the using of phononic crystal as biosensors to be applied in biochemical sensing for many biomaterials such as (NaI, H_2O_2, MNE, Acetic acid, milk contents, proteins, Amino acids, Glucose and Glycine) and maybe some heavy metals as dangerous pollutants in water. We expect based on the previous studies, the device of phononic crystal can introduce a high sensitive, **low cost (with very simple materials)**, easily usable and flexible biosensor. Also, such senor can be used to ***sense water pollutions*** with the highest sensitivity compared with and conventional techniques. Finally, By using the transfer matrix method, the transmittance spectra were theoretically determined (TMM).

1. Research Objectives

1. In the present work, the influences of several paramters such as concentration, type and temperature of many liquids and biomaterials such as NaI, H_2O_2, MNE, Acetic acid, milk contents, proteins, Amino acids, Glucose, Glycine and heavy metals are analyzed and discussed. Also this project focuses on correlating and comparing between the transmission properties of pure and impure bio-liquids inside a defect layer in the PnCs. Moreover, we especially pay attention to numerical calculations based on concept of defect mode and resonance phenomenon that demonstrate the extraordinary acoustic transmission through bio and chemical materials.
2. More attention will be paid to fabricate and characterize the sensitivity properties of phononic crystals in 1D phononic crystal structures and their novel properties in sensor applications. Transition between different structures of phononic crystals allows us to use these composites materials in advanced application in oils detection and environmental pollution measurements.
3. We focus in this project to use green and low cost materials to propose the biosensor to be eco-friendly and has the merit of ease of fabrication.
4. Many performance paramters such as sensitivity, Figure of emrit, detection limit, quality factor and signal to noise ratio will be calculated to show the properties of the proposed biosensors.

2. Literature Review

Phononic crystals (PnCs) are artificial periodic structures that are applied to regulate sound wave propagation [1,2]. The phononic bandgap, which prevents sound waves from passing through the lattice, is PnCs most significant feature [3,4].The tenability of these gaps is determined by the mechanical properties of the PnCs constituent materials [5,6]. Such innovative structures have recently received a lot of attention because of their ability to control not only sound waves [7,8]. Examples of PnCs use and applications in engineering include liquid sensors, waveguides seismic wave reflection, acoustic cloaking, sensors, temperature sensors, filter multiplexer devices, actuators, heat isolation systems, and the creation of acoustic Met materials [9–12].

Nowadays, The creation of acoustic sensors, which are regarded as a special framework for liquid sensing purposes, is one of the most fundamental uses of PnCs. Using PnCs-based sensors, liquid types, concentrations, and physical features can be identified and sensed. for example, a sensitive biosensor that measures the temperature of methyl nonafluorobutyl ether (MNE) in the range of 10 to 40 °C utilising a two-dimensional triangular lattice solid/fluid phononic crystal (PnCs) is demonstrated [13,14]. A new sensor platform based on a PnCs cavity was created by R. Lucklum et al. to measure the qualities of gasoline [13,14]. sensors are an integral part of all technological applications, necessitating interdisciplinary study in engineering, physics, chemistry, and biology for the production of sensors. A unique sensor platform is the creation of sensors based on changes in the acoustic properties of liquids, such as density and sound speed, which can vary more significantly than other properties like the refractive index in photonic crystals and plasmonic sensors [15,16]. The word "biosensor" refers to a device that transforms biological signals into electronic or mechanical impulses. Based on changes in their physical properties, many liquids and biomaterials, such as acidity, hydrogen peroxide, blood glucose, and heavy metal pollution in water, can be examined and detected by many types of biosensors [17,18]. Sensors are produced based on the modification of several physical properties, such as sound speed, and viscosity to achieve these sensing applications. Recently, the ability to use and realize a sensor based on its acoustic properties has attracted attention in various fields [3,4]. Different types of structures and designs have been introduced to realise such acoustic sensors. For example, Zubtsov et al. developed a PnCs sensor that could detect the level of a water/1-propanol solution [19]. Additionally, a one-dimensional (1D) phononic crystal (PnCs), a biosensor for estimating acetone concentrations in water, was developed [20]. A design for a very sensitive water-ethanol mixture sensor based on phononic crystals has already been proposed [21]. Also a sensor is effective at identifying and measuring the physical characteristics of biodiesel. For the detection of an ethanol-water mixture as well as 1D biosensors, a 2D PnCs sensor was described [21].

Quasiperiodic sequences for Phononic crystals structures have more interest in different experimental and theoretical PnCs studies due to their remarkable effects, such as more extended and multiple phononic band gaps (PBGs) with the appearance of strong resonances spectrum [22–24]. For instance, by adding a cavity inside the PnCs, the periodicity of the structure was broken and many resonance modes were added through the PnCs-BG, which increased the novelty of these PnCs structures more than the conventional ones. Recently, researchers' interest in quasi-periodic structures in the field of phononics has increased. The design and control of the structure's features are given an additional degree of flexibility for periodic structures with specific ordering patterns [25,26]. Quasi-periodic structures lack translational symmetry with special ordering patterns that give us more design flexibility and control of the features of the structure. Several different rules, including Cantor, Dodecanacci, Fibonacci, Rudin Shapiro, and others, can be applied to create quasi-periodic sequences [27,28]. To create wide phononic band gaps, quasi-periodic structures may be more efficient than periodic designs. Additionally, they can readily make waveguides and cavities in PnCs and are the greatest option for tuning transmission modes. Solid-solid and solid-fluid structures have so far both been able to achieve quasi-periodic structures in 1D and 2D PnCs [26–29]. Band gaps with large resonance peaks are also observed in quasi-periodic structures, which can substantially confine acoustic waves. As a result, the quasi-periodic PnCs are attractive candidates for overcoming the low-frequency restrictions of acoustic structures. One of the most significant and well-known quasi-periodic PnCs structures is the Fibonacci quasi-periodic PnCs

[27,28] These quasi-periodic PnCs offer self-likeness energy spectrum, localization, and efficient and tunable phononic bandgaps (PBGs).

In this project, the transmission spectra of a one-dimensional PnCs sensor are examined to determine how variations of many bioliquids concentration affect them. We adopted the transfer matrix method (TMM) in this investigation. To accurately differentiate between many bioliquids, we will construct a periodic and quasi-periodic multilayer PnCs structure. For each concentration, the sensitivity (S), quality factor (Q), and figure of merit (FOM) sensor performance metrics will be evaluated and recorded. The final results might offer a simple method for determining varied bioliquid mixture concentrations using inexpensive, flexible components and no lead time sensing application. Our designed sensors are also favoured over electrical or optical ones because they do not have any electronic components in their construction, and operate in extreme conditions and at high temperatures.

3. Research Methodology

The methodology of the project is divided in the following branches:

1. The interactions of the elastic waves with phononic crystals will be solved analytically and numerically using some mathematical methods as transfer matrix method (TMM), finite element method (FEM) in 1D phononic crystals. The results will be compared with the available experimental data. These studies about 1D and 2D phononic crystals may be suitable for some applications of the aforementioned theories which will be applied on relevant materials in the published data.
2. The ability of producing a simulated data of 1D and 2D phononic crystals using different codes that had been performed using different software's.
3. The capability of the phononic crystals will be demonstrated with a one-dimensional arrangement with defect layer and liquid filled cavities and a two-dimensional periodic arrangement of liquid filled holes in a solid matrix. The producing data will be performed using different techniques and methods such as transfer matrix method and plane wave expansion method.
4. Studying and characterizing different 1D phononic crystals structures depending the available and flexible materials.
5. These studies about 1D phononic crystal Biosensors will be utilized to introduce some new approaches for new and simple devices for the studying different biomaterials and conventional biosensors in our society.

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