ELECTROMAGNETIC RADIATION DETECTION FROM FERROELECTRIC CERAMICS FOR WIRELESS SENSING APPLICATIONS

A THESIS

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Dedicated to my Parents and Lord Shiva

Declaration by the Research Scholar

I hereby declare that the entire work embodied in this thesis entitled "**Electromagnetic radiation detection from ferroelectric ceramics for wireless sensing applications**" is the result of investigations carried out by me in the **School of Engineering**, Indian Institute of Technology Mandi, under the supervision of **Dr. Vishal S Chauhan and Prof. S.C Jain** for the award of the degree of **Doctor of Philosophy** and that it has not been submitted elsewhere for any degree or diploma. In keeping with the general practice, due acknowledgements have been made wherever the work described is based on findings of other investigators.

Place: I.I.T. Mandi (H.P.)

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Thesis Certificate

I hereby certify that the entire work in this thesis titled "**Electromagnetic radiation detection from ferroelectric ceramics for wireless sensing applications**" has been carried out by **Sumeet Kumar Sharma**, under my supervision in the **School of Engineering,** Indian Institute of Technology Mandi for the award of the degree **Doctor of Philosophy**. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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ABSTRACT

Materials oriented advancement in science and technology plays an important role as a driving force for innovation in various aspects of the human civilization. Materials not only need to possess high reliability but should also have some additional functionalities such as damage restrains, self-diagnosis, self-repair and notification of residual life. The external loading conditions and presence of inclusions, impurities and defects lead to the formation of cracks and their propagation when there is an increase in stress level. Hence it is presumed that an engineering component can sometimes fail suddenly without any prior warning as a consequence of these pre-existent defects which can be tedious to detect most of the times. Every infrastructure is generally designed and built to carry out a specific kind of task for a given operative and loading conditions. To carry out its designed task effectively and safely the service life is an important factor to be taken care of. There are many factors which affect the proper functionality of the infrastructure such as ageing of host material, extreme use, overloading and other environmental factors. Thus the possible preventive measure is to determine location, size and severity of the deformation.

Structural health monitoring (SHM) is a monitoring technique which aims to identify, locate the damage to prevent the infrastructure from further failure and to predict the remaining life of the structure. There are several tools used for the SHM viz. tap test, guided wave test, acoustic emissions monitoring, electrical signals monitoring etc. [1-3]. Among these, deformation induced electromagnetic radiation (EMR) emission detection has evolved as an intriguing research area. Electrical signals were first observed from ionic crystals in the early 19^{th} century by Joffe et al. [4] and were further explored by a number of authors [5-7]. Later electromagnetic radiation (EMR) from materials was directed toward the usage of this phenomenon in crack propagation monitoring [8], earthquake prognosis [9], snow avalanche prediction [10], stress sate monitoring of coal mines [11], predicting rock burst [12] and last but not the least for developing an efficient deformation/failure monitoring technique [13]. Till now lack of proper understanding of these emissions both from experimental as well as theoretical point of view restricts this technique being used on a large scale with respect to deformation monitoring perspective. For using this technique to serve humanity on a large scale a broad knowledge base for these electromagnetic emissions is necessary and needs further exploration. A good monitoring system will help to determine the damage in the exact particular component and with good monitoring system location and extent of damage can be

easily predicted. These techniques are very helpful in preventing the failure from turning into a fatal one and will also help in saving the time of the people working with the system.

Keeping the aim of exploring materials which can give maximum EMR signal (which will be used for deformation monitoring) under slightest stimulus and considering the widespread use of ferroelectric/piezoelectric materials as sensors and actuators these materials are investigated for the detection of deformation induced electromagnetic radiation. These materials could be embedded in the main material paving the way for the development of smart composites. The EMR emissions have been detected from ferroelectric materials using the non-contact detection technique. Thus the present dissertation showcases the EMR emission detection from ferroelectrics under different type of loading conditions along with simple mathematical model.

To start exploring the ferroelectric materials for their EMR response we have proceeded with the simplest possible instrumentation. Firstly, we have investigated electromagnetic radiation (EMR) signals from soft (SP 5A) and hard (SP 4) PZT ceramics using alternating electric field as external stimulus. EMR signals were measured when the alternating electric field was applied on the samples. In all the experiments discussed in the dissertation the EMR signals have been measured using a non-contact circular loop antenna made up of copper.

Secondly we have also investigated EMR emissions from (1-x)($Bi_{0.5}Na_{0.5}TiO_3$)–x($BaTiO_3$) (x = 0.04, 0.05, 0.06, 0.07 & 0.08) lead-free piezoelectric ceramics. Compositions near the morphotropic phase boundary 0.94($Bi_{0.5}Na_{0.5}TiO_3$)–0.06($BaTiO_3$) (BNT-6BT) are studied. Effect of the strength and frequency of applied electric field has been investigated for both lead-based and lead-free ferroelectric ceramics. EMR signals have been found to increase with the increase in strength and frequency of applied electric field.

After the experimental investigations a mathematical model for the EMR emission from ferroelectric materials when subjected to alternating electric field has been developed. 180° oscillation of dipoles has been considered as the basis for the formulation of the mathematical model. For comparison with theoretical model the experimental results of EMR signals from well-known lead-free ferroelectric $BaTiO_3$ and lead-based ferroelectric soft (SP 5A) and hard (SP 4) PZT have been compared with the results obtained from the developed mathematical model. The experimental results in both the cases have found to be in agreement with the theoretical results.

Hereafter EMR emissions from soft and hard PZTs under impact loading at room temperature has been detected. In addition to that effect of the change in the strength of d.c poling field on the EMR voltage signals has also been analyzed. Amplitude of EMR signals has been found to increase with the magnitude of impact loading and d.c poling field. Soft PZT (SP-5A) has been tested for EMR signals detection under impact at low temperatures (300 K to 203 K). EMR amplitude showed a decreasing pattern with lowering of the temperature at which the sample was placed. Low temperatures restrict the dipole movement and reduced acceleration of charges under impact at low temperatures corresponds to the decrease in amplitude of EMR signals. Thereafter EMR signal detection from soft (SP 5A) and hard PZT (SP 4) ceramics under impact loading at temperatures ranging from room 288 K to 514 K has been done. Thermal depoling and increase in the volume fraction of non-ferroelastic domains at higher temperatures reduces the amplitude of EMR signals.

The above mentioned work has been categorized into seven chapters and a chapter wise breakup of the work is briefly summarized below:

The general introduction of the topic and the motivation behind this work is presented in Chapter I and in Chapter II a detailed literature review is presented which shows the earlier work done by the researchers in the field of deformation induced electromagnetic radiation (EMR) detection.

Chapter III explores the lead-based and lead-free ferroelectric ceramics for electromagnetic radiation when subjected to alternating electric field. Electromagnetic radiation has been detected for the increase in the strength of alternating electric field, change in the frequency of electric field and with the change in the position of the antenna w.r.t the sample.

Chapter IV showcases the mathematical model for the EMR emissions from ferroelectrics when subjected to alternating electric field. The mathematical model has been validated with the experimental observations obtained in case of lead-based as well as lead-free ceramics.

Chapter V shows the investigations of soft and hard PZT for the EMR emission detection under impact loading at room temperature. In addition, effect of extent of poling on the EMR emission from soft and hard PZT has been analyzed.

Chapter VI presents the EMR emission detection from soft and hard PZT at low and high temperatures.

Chapter VII shows main conclusions and future scope of the thesis.

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TABLE OF CONTENTS