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A Review on Various Piezoelectric Materials for Current Applications

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***Abstract*—In general, everyone wants new technology to survive in this competitive world. In the segment of instrumentation, the transducer is one of the electrical devices well suited for domestic and small-scale industry applications. Uniqueof the new technologies in the transducers by means of piezoelectric transducer is widely used in the electrical and mechanical field applications. So in this review paper, various piezoelectric materials are discussed along with their physical properties and benefits. Current applications with piezoelectric transducers are deliberated and evaluated based on the physical properties of these piezoelectric materials.**

***Index Terms*— Piezoelectric transducers, Piezoelectric materials, lead zinconatetitanate, Quartz, Rochelle salt.**

I. INTRODUCTION

The reduction of fossil fuels and its antagonistic effects on the atmosphere can lead the researchers near the unconventional energy sources have expanded popularity in the civilization. Preliminary the well-known solar photovoltaic cells to the wind energies, and biogas plants have already being effectively recognized and engaged for the power generation. For power supply requirements of the transportable devices the human utilize, new methods have been originated out to satisfy the requirement. Piezoelectric materials and their properties have played a key role in cracking such difficulties. The transformation of electrical energy from mechanical energy can be done by the utilize of piezoelectric resources.
Advantages of Piezoelectric transducers:

1. This transducers have simple arrangement
2. This transducers don’t require exterior voltage resources
3. This transducers have companionable with MEMS
4. This transducers have high voltage at output side
5. This transducers don’t require machine-driven constraints
6. This transducers have extensive frequency range

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Currently, transducers are developed and available in different types and their production and performance depends on the materials 'characteristics used in the process [1]. Especially various piezoelectric materials designed and those materials can transform mechanical energy into electrical energy; but, the designed materials 'characteristics for piezoelectric transducers for specific applications are found commercially expensive. But in late 1940's to 2000 years so several different equipment are engaged for applications driven by the piezoelectric transducers with different types of piezoelectric materials [2].
The block diagram of the piezoelectric transducer consisting 3 phases with three different power electronic devices likes as rectifiers, DC-DC converters and inverters. Generally voltage produced through the piezoelectric transducer in mill volts range. To boost this voltage with the help of boost converter into volts & kilo volts and again convert this DC voltage into AC voltage with the help of inverters. Finally feed this AC voltage to grids, domestic loads and etc. But in piezoelectric transducer, selection of the piezoelectric substantial is important aspect regarding the load side applications feed by it.

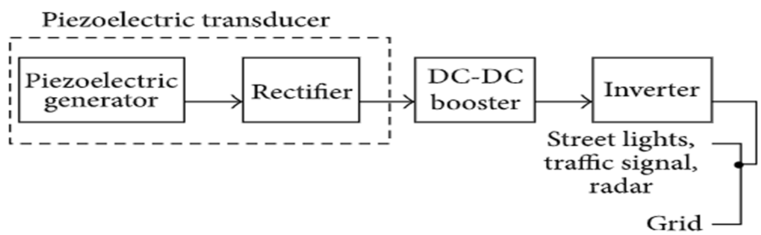

Figure.1 Block diagram of the piezoelectric transducer

The block diagram of the piezoelectric transducer consisting 3 phases with three different power electronic devices likes as rectifiers, DC-DC converters and inverters. Generally voltage produced through the piezoelectric transducer in mill volts range. To boost the voltage with the help of boost converter into volts & kilo volts and convert this DC voltage into AC voltage with the help of inverters. Finally feed this AC voltage to grids, domestic loads and etc. But in piezoelectric transducer, selection of the piezoelectric substantial is important aspect regarding the load side applications feed by it. Entire this review paper organized in five sections: first section is introduction and second section explains the collected work evaluation of the piezoelectric materials. The comparison of the properties among Quartz, Rochelle salt and PZT and Selection of various piezoelectric materials for current applications viewed in second section and third section. Finally fourth section concludes this paper.

II. Literature Review

Piezoelectricity is the possessions of dielectric constituents to materially deform after an electric field is exist, or on the further point, to harvest an electrical energy once they are mechanically deformed is well-known as piezoelectric effect. There are a variability of materials which illustrate this occurrence like as natural quartz, polycrystalline piezoceramic, polyvinylidene polymer, and wood. There are various man-made and usualpiezoelectric materials presently in utilize. Some of the regular piezoelectric resources are Rochelle salt,Topaz, Tourmaline, Potassium niobate (KNbO3), Lithium tantalate ($LiTaO_3$), Lead titanate ($PbTiO_3$), Lead zirconatetitanate (PZT) is presently the best exploited piezoelectric materials and utilized in numerous applications.In 1940's piezoelectric transducers consisting a piezoelectric materials like as quartz, Rochelle salt, ammonium dihydrogen phosphate (ADP),tourmaline and etc. utilized for electrical and mechanical applications. Barium titanate piezoelectric material growth is increased with higher piezoelectric coupling and extensive working temperature range in 1957's [2].Zinc oxide and cadmium sulphide piezoelectric material is used in mid of 1961 with wide operating temperature range and low dielectric constant for sonic and ultra-sonic applications [3]. From [4] the following piezoelectric materials with their characteristics are viewed in Table. I.
By, based on the data available in the above table provides the information regarding the piezoelectric materials with their characteristics. Most of the cases family of PZT (lead zinconatetitanate) with specific chemical compositions are used as piezoelectric materials .Especially in a crystal structure of the PZT with *noncentro symmetric* crystals exhibits the piezoelectric effect by 20 crystals out of 32 crystals. Every unit cell in classic noncentrosymmetric crystal structure such as $CaTiO_3$ (calcium titanate) can produce non-zero charge. The titanium ion placed inside the crystal can develop electric polarity with other ions like oxygen and barium in a

TABLE I. PIEZOELECTRIC MATERIALS – CHARACTERISTICS

Various piezoelectric materials	Characteristics
PZT-5H	Piezoelectric coupling and High permittivity
$Na_{0.5}K_{0.5}NbO_3$	High acoustic velocity
PZT-7A	Low permittivity
PZT-6B	High mechanical
$PbNb_2O_6$	Low mechanical
PZT-6A	Temperature stability
PZT-6B	Time stability
PZT-8	Low dielectric loss at high electric drive

unit cell with dielectric dipole momentum. Finally piezoelectric effect is exhibited by these ions shifted from one position to another in a unit cell of a crystal.

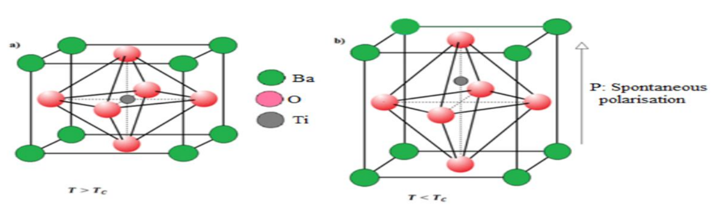

Figure.2 Crystal structures of PZT with (a).Operating temperature lower the curie temperature and (b).Operating temperature above the curie temperature

It is marked from [2],for piezo-energy harvester applications the composition (P-5C) piezoelectric material is best among followed by Pz-28, Pz-26, and etc.by based on the TOPSIS ranks and this piezoelectric material utilized in the late 2000 centaury.In 2010 the piezoelectric material PZT-5K is best for the applications of piezoelectric actuators, followed by PZT-5M, PZT-5J and etc. by based on the TOPSIS ranks in [2].From [2] the piezoelectric material PZT-7A is best among strictly followed by PZT-8, PZT-7D and etc. for piezoelectric sensor applications by based on FOM method in late 2015's.

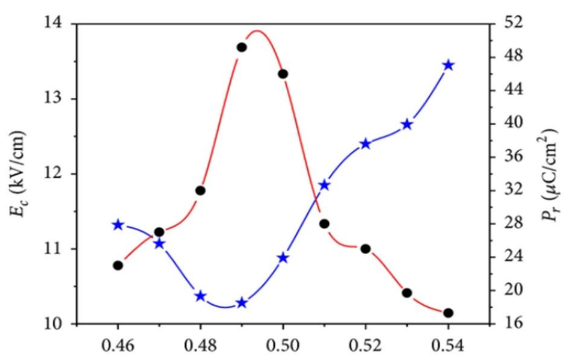

Figure.3 Physical properties of PZT

The structure of PZT piezoelectric material nearby the morphotropic phase periphery achieved in the ratio of Z_r/T_i = 49/51. This ratio can decides the physical properties (electromechanical properties) with low coercive field kV/cm^{-1} and high remnant polarization ($\mu C{\cdot}cm^{-2}$). These physical properties of PZT may suitable for hard piezoelectric material applications with high power driven to the electrical loads [5-7].

In the year of 2016 Quartz is unique of the hard and single crystal piezoelectric material with silicon and oxygen atoms and frequently used for the applications of electrical and mechanical field. Generally quartz is graded into two types such as normal quartz and cultured quartz through impurity level lower one fragment of a thousand. Most of the cases natural quartz is used in crystal form in piezoelectric transducer by based on its characteristics such as high dielectric strength and wide operating temperature range and these improvements are also summarized in1980's [8].The crystal structure of the quartz is viewed in hexagonal shape in two dimensional.

Generally crystal of quartz contains silicon and oxygen ions. The silicon ion placed inside the crystal can develop electric polarity with other ions like oxygen in a unit cell with dielectric dipole momentum. Finally piezoelectric effect is exhibited by these ions shifted from one position to another in a unit cell of a crystal.

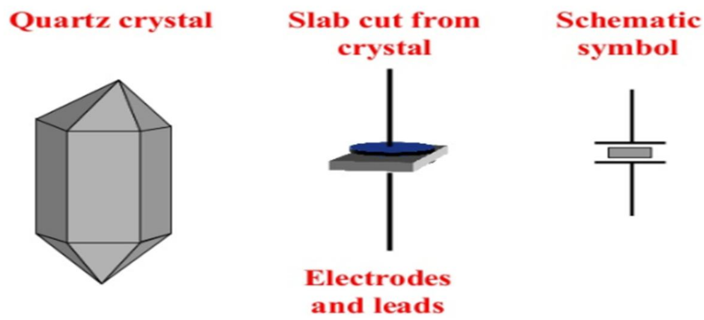

Figure.4 Crystal structure of the quartz

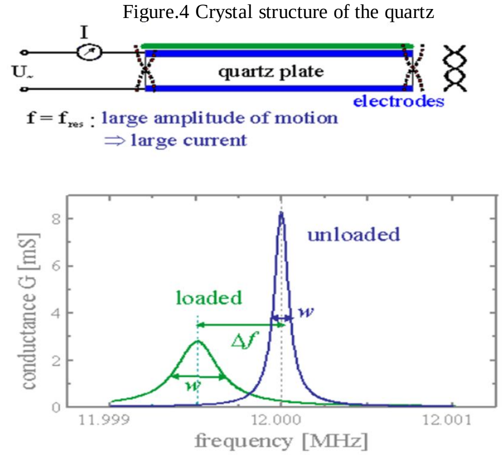

Figure.5 Physical properties of quartz

The physical properties of quartz are mail dependences on two parameters such as conductance and frequency. One can apply force on the quartz it can release a conductance in less magnitude. But suddenly removing that force on the quartz can generate a conductance in huge manner with reverence to the magnitude of frequency of the quartz plate [9-10].

In 2016 the Rochelle salt (Sodium Potassium tartrate) is also one the single crystal piezoelectric material and mostly used for the applications of electrical and mechanical field. The characteristics of Rochelle salt such as high electromechanical coupling and narrow operating temperature range [11] [12]. The crystal structure of the Rochelle salt is viewed in rhombic structure. Generally crystal of Rochelle salt comprises sodium, potassium and titanium ions. The titanium ion placed inside the crystal can develop electric polarity with other ions like sodium, potassium in a unit cell with dielectric dipole momentum. Finally piezoelectric effect is exhibited by these ions shifted from one position to another in a unit cell of a crystal.

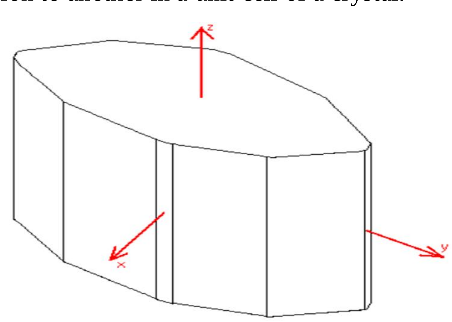

Figure.6 Crystal structure of the Rochelle salt

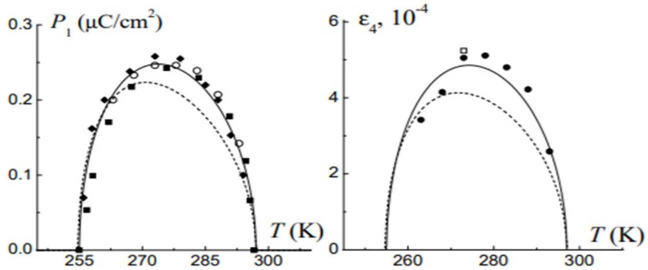

Figure.7 Physical properties of Rochelle salt

Coming across with the physical properties of Rochelle salt, 2significant parameters are considered as, spontaneous strain ε4 and spontaneous polarization P_1 with the aid of a modified Mitsui model. Following figure can explains how the Temperature dependence of spontaneous polarization (left) and spontaneous strain ε4 (right) of Rochelle salt: ◦ — [13]; ■ — [14]; — [15]; — [16], • — ε4 = P1d14/χ σ 11 [12]. Solid lines regarding the graph is explained with modified Mitsui model in [17] and dotted lines regarding the graph is explained with Mitsui model in [18]. The physical properties of the Rochelle salt are expressed in [19-21].

III. Comparison of the Properties among Quartz, Rochelle Salt & PZT

This section describes the comparison of Quartz, Rochelle salt and PZT with its properties. Generally, every piezoelectric crystals having the properties like appearance, odour melting and boiling points. In below table.2comparison of the properties among Quartz, Rochelle salt and PZT are evaluated and analysed for piezoelectric transducer applications.

TABLE II. COMPARISON OF THE PHYSICAL PROPERTIES AMONG QUARTZ, ROCHELLE SALT AND PZT

Parameters	Quartz	Rochelle salt	PZT
Appearance	White	White	Yellow
Odour	None	None	None
Melting point	1710°C	70°C – 80°C	1350°C
Boiling point	2330°C	220°C	-112°C
Specific gravity	2.65	1.7	3.15
Hardness (Mho's scale)	7	1	3.6

From table.3, it is concluded that the less cost and high temperature range is associated with the PZT materials. Nevertheless the high cost and high temperature range is associated with the quartz materials. On the other hand the low cost and low temperature range is associated with the PZT materials. The aspect like deformability is high for quartz and low for Rochelle salt and PZT. The piezoelectric charge constant is same for these three materials. Based on the literature review and properties of these materials can lead to form an applications regarding the present power supply requirements in society.

TABLE III. COMPARISON OF THE GENERAL ASPECTS AMONG QUARTZ, ROCHELLE SALT AND PZT

Parameters	Quartz	Rochelle salt	PZT
Deformability	High	Low	Low
Piezoelectric charge constant (d_{33})	High	High	High
Temperature range	High	Low	High
Cost	High	Low	Very low

TABLE IV. APPLICATIONS OF QUARTZ, ROCHELLE SALT AND PZT

Applications	Quartz	Rochelle salt	PZT
Battery electric vehicles	Not suitable	Not suitable	Suitable
Hybrid electric vehicles	Not suitable	Not suitable	Suitable
Aerospace applications	Suitable	Suitable	Not suitable
Power supplies	Suitable	Not suitable	Suitable
MEMS	Suitable	Suitable	Suitable
Medical Applications	Not suitable	Not suitable	Suitable
Electro-acoustic devices	Suitable	Suitable	Not suitable

From table.4, it is cleared that due to the availability of low cost, high specific gravity high temperature range, high melting points, and low boiling points regarding the PZT can play key role in the applications of Electric Vehicles (EV's), Power supplies, and etc. But quartz also the properties like high temperature range, high melting points and boiling points, good hardness but cost of the quartz is high compared with the PZT. That's the reason generally quartz materials are employed in aerospace applications, electro-acoustic applications, and etc. On other hand Rochelle salt also having properties like low cost and good piezoelectric charge constant leads the Rochelle salt employed in the area of MEMS and etc.

A. Selection of various piezoelectric materials for current applications by based on above discussion:

By based on the evaluating the properties of Quartz and Rochelle salt in table.2 and 3these materials come under the soft piezoelectric materials and those materials are well suited in following applications such as sensors, aerospace applications, and etc. The properties of PZT evaluating from the table.2 and 3 suggests like that this PZT materials comes under the hard piezoelectric materials and those materials are well suited in following applications such as medical industry, EV's and etc.

IV. CONCLUSIONS

This review paper provides the basic idea and properties of the Quartz, Rochelle salt and PZT piezoelectric resources used in piezoelectric transducer applications. The literature review regarded in this paper gives the era of piezoelectric materials utilized in past years. The entire literature review gives the positive response for the Quartz, Rochelle salt and PZT piezoelectric materials. As a final point this paper resolved that Quartz and Rochelle salt are preferred for soft piezoelectric material based applications and PZT is preferred for hard piezoelectric material based applications.

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