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MAKER: Piezoelectric Crystal Experiments for High School Science and Engineering Students

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MAKER: Piezoelectric Crystal Lesson/Experiment for High-School Science and Engineering Students

Abstract

This paper describes the design, construction, and evaluation of an instructional module for K-12 science and engineering students on energy harvesting using piezoelectric crystals. The module consists of a combination of lecture and activities. The lecture component covers the history of piezoelectric materials, how they work, how to use them to generate energy, and how to measure the amount of energy generated. The activity component includes how to make a piezoelectric crystal, and an embedded assessment, pre-assessment, and post assessment. The module was used in three engineering classes. Students worked in teams to prepare crystals and successfully tested them. An evaluation of the module indicated that a high level of learning was achieved. In addition, the students all enjoyed the hands on experience. This module was created as a result of attending a Summer Research Experiences for Teachers program at Texas A&M University in 2014.

Overview

In 1880 the Curie brothers, Jacques and Pierre, demonstrated for the first time the: **piezoelectric effect**: the application of a mechanical stress that can generate an electric charge dependent on the material in question[1]. **Piezo**[2] in *Greek root meaning "subjected to pressure."* The Curie brothers focused their efforts on crystals such as tourmaline, quartz, topaz, cane sugar, and Rochelle salt. In 1881 Gabriel Lippmann mathematically deduced the converse piezoelectric effect using fundamental thermodynamic principles. That is:

> *If I hit (deform) the crystal….. I produce an electric charge*
> *Therefore: If I produce electric charge I deform the crystal*

Shortly hereafter the Curie brothers confirmed the existence of Lippmann's deduction. Research of crystals went on for about the next 30 years, resulting in a book by Woldemar Voigt entitled *Lehrbuch der Kristallphysik* (Textbook on Crystal Physics) that detailed the 20 known natural crystals that express piezoelectricity and defined the piezoelectric constants using tensor analysis[3]. Historical applications of Piezoelectricity includes (a) phonograph (early record player), (b) first sonar (France 1917), (c) ultrasonic time-domain reflect meters (to identify flaws in cast structures), and (d) telephone[4].

Lesson Title: "Shocking Crystals" Future Technology with Piezoelectricity

Introduction: Piezoelectricity is the production of charge built up, in naturally occurring and synthetic crystals, ceramics, and even in your DNA and bone due to applied mechanical pressure. Piezoelectricity and the Piezoelectric effect today are crucial concepts that have useful applications in: the production and detection of sound such as electric pickups, and microphones, **nanotechnology**, linear motors and rotational motors used in precision optics, electric ignitions such as used in cigarette lighters and barbecue grills. Current applications of piezoelectricity are investigated through exciting short videos demonstrating the piezoelectric effect. In addition this lesson gives you an understanding of the history and application of Piezoelectricity.

Engineering Connection: In our world today we are always trying to find the next big advancement in technology and engineering. Products are getting faster, more efficient and most noticeably smaller! Our electronic devices are interactive and wearable[5]; they are capable of wireless communication and able to connect us to the World Wide Web via satellites. Students will see how engineers were able to apply this piezoelectric effect to modern devices that improve the precision of motors to the micrometer scale. This is applied in our electronic devices that need extreme accuracy and are now able to be much smaller. Engineers are able to design smaller less expensive and more effective devices thanks to the advancements in piezoelectric motors. The world's energy crisis has not been solved, but there is a push for the greatest minds and the next generations to find a way to reduce our dependence on fossil fuels and rely more heavily on clean renewable energy. Numerous research applications are currently using piezoelectric materials in an effort to harvest energy in nature through wind[6] and mechanical vibrations that are overlooked daily. Maybe one day in the future you will be powering your devices from the "good vibrations" we create by walking, running, driving, riding the subways, and even "cutting a jig" on the dance floor! For example, Babolat has developed a smart racquet that uses piezoelectric sensors along with accelerometers and gyroscopes to provide game performance feedback to the player via smart phone[7].

Figure 1. Babolat Pure Drive Play tennis racquet with smart phone.

Learning Objectives: After this lesson, students should be able to (a) describe the piezoelectric effect, (b) describe the reverse piezoelectric effect, (c) discuss engineering and technological advancements made by piezoelectric materials, and (d) generate ideas on how to harvest energy using piezoelectric materials

Vocabulary / Definitions

Word	Definition
Current	Current is actually the flow of electrons or conventionally speaking the positive charge in a direction opposite to that of electrons
Lead Zirconate Titanate (PZT)	**Lead zirconium titanate** is an inter-metallic inorganic compound. Also called **PZT**, it is a ceramic perovskite material that shows a marked piezoelectric effect, which finds practical applications in the area of electro ceramics. It is a white solid that is insoluble in all solvents

Word	Definition
Piezoelectric effect	The polarization of non-conducting materials when they undergo mechanical strain, and the mechanical strain when subjected to an electrical current
Piezoelectricity	Electrical current produced by the piezoelectric effect
Quartz	One of the most common minerals (Silicon Dioxide SiO_2), commonly used in radio transmitters
Rochelle Salt	Potassium sodium tartrate. A piezoelectric crystal used in microphones and earpieces during the mid-20th century
Transducer	A device that receives one type of energy signal and converts it to a another type of energy signal
Voltage	A type of "pressure" that drives electrical charges through a circuit.

Procedures: Give the students the Piezoelectricity Pre-Assessment to evaluate their knowledge of piezoelectricity prior to the introduction/motivation. Collect the assessment for use with the post assessment to evaluate the students' knowledge gain of piezoelectricity. Once the pre assessment has been administered and collected from students; proceed with the video and activity.

Lesson Warm-up

To enhance students' interest, the following videos can be shown before beginning the lab activities: (1) Toyota ad for green design using piezoelectric materials http://goo.gl/2lPUOA, and Green Micro Gym Portland, Oregon http://goo.gl/W2YRE8

Suggested Preparation

Teachers can provide a $2 demonstration of piezoelectric transducer powering an LED by purchasing a $1 window alarm (the battery powered one that alerts when the window has been open) and a $1 LED light products from a dollar store (such as an LED clip on a book light). Disassemble the window alarm to and remove the ceramic piezoelectric transducer[8] (Figure 2), being careful not to remove the wire leads from the transducer. Then disassemble the LED light product and wire the LED leads to the ceramic piezoelectric transducer leads. Now just tap on the transducer and you should see the LED light up! The LED and ceramic piezoelectric transducer can be mounted to a block of wood for a classroom display that students can pass around and test out. If mounting to a block of wood, glue a rubber washer underneath the transducer then glue the washer to the block of wood. This will allow enough room for the transducer to bend when impacted, which is important because the mechanical strain (bending) is what generates the piezoelectric effect.

If a guitar pickup, amplifier, and acoustic guitar are available, the guitar can be played to demonstrate how the piezoelectric effect works in musical instruments. Other possibilities include amplifying a "trash can drum," a plastic hair comb, or even a desk as students knock on it. Common applications of a piezo electric transducer are blinking lights, speakers, signals, and amplitude and frequency pick-ups.

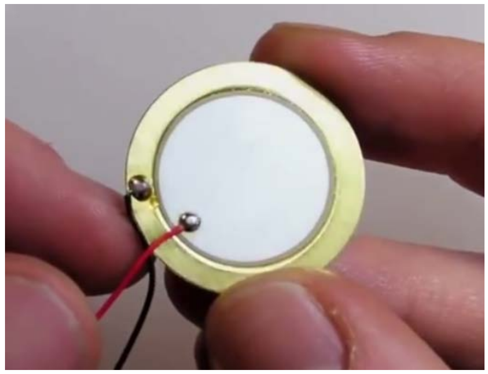
Figure 2. Ceramic Piezoelectric Transducer.

Lab Activity

This section describes how to make a Rochelle salt crystal and generate electricity through the deformation. The recipe for making Rochelle salt crystal is below.

Materials needed include:
- Safety glasses
- Latex gloves
- Spoon/stirring rod for stirring the solution
- Half teaspoon measuring spoon
- One cup of distilled water (to protect the purity of the crystals)
- Heating element (hot pad; Bunsen burner; electric burner etc.)
- Fahrenheit thermometer
- 2 cup (minimum size) heat safe glassware for mixing solution in water @ 180^0F
- One coffee filter to remove precipitate from solution after heating
- 7oz of potassium bitartrate, also known as cream of tartar. This is most cost effectively bought in bulk from chemistry supply companies such as Finn Scientific; Fisher Scientific; or Wards.
- Medium or large sauce pan (used with tap water to heat the glassware with the distilled water solution)
- Tap water to use in the sauce pan (enough to cover about half-way up the glassware in the sauce pan)
- Sodium Carbonate "Soda Ash" (Can be purchased from arts and craft stores as "Soda Ash" or from chemistry supply companies such as Finn Scientific; Fisher Scientific; Wards etc.)

Instructions:
1. Measure 1 cup of distilled water in the Pyrex measuring cup.
2. Add 7oz of potassium bitartrate to the distilled water and stir it well so that the particulate is in suspension and not settled on the bottom of the measuring cup.
3. Place the measuring cup into the sauce pan and add tap water to the sauce pan (careful not to get the tap water in the measuring cup) this will act as a double boiler. Add only enough tap water to sufficiently surround the measuring cup, but not so much that it causes the measuring cup to float.

4. Heat the sauce pan with tap water to 180^0F. Use a thermometer to monitor the temperature.
5. When the solution has reached 180^0F and stayed steady, add a half teaspoon of sodium carbonate to the measuring cup. This will fizz and bubble up. As the fizzing begins to settle, stir the solution well.
6. Repeat the process of adding a half teaspoon of Sodium Carbonate and stirring the solution until the solution no longer fizzes and becomes clear. (There may be a bit of particulate on the bottom of the measuring cup, but this is fine.)
7. Once the solution has stopped fizzing when adding the sodium carbonate and has become clear, remove it from the heat.
8. While the solution is still hot, pour it through a coffee filter to remove any undissolved Sodium Carbonate particulate from the solution.
9. Pour the filtered solution into a plastic container and cover it lightly to prevent contaminates from falling into the solution.
10. Store the solution overnight in a safe cool place. The next morning you should have several good Rochelle salt crystals to choose from.
11. Rochelle salt crystal selection:
    - In the morning, pour off the remaining solution into another container. Dry off each crystal to prepare them for selection.
    - Select all crystals that that are smooth on their sides and rectangular in shape.
    - Of these, pick the clearest crystal.

Figure 3 shows a piezoelectric Rochelle salt crystal made in the lab using sodium carbonate using this process. Figure 4 shows students making the crystals.

Figure 3. Piezoelectric Rochelle salt crystal made in the lab.

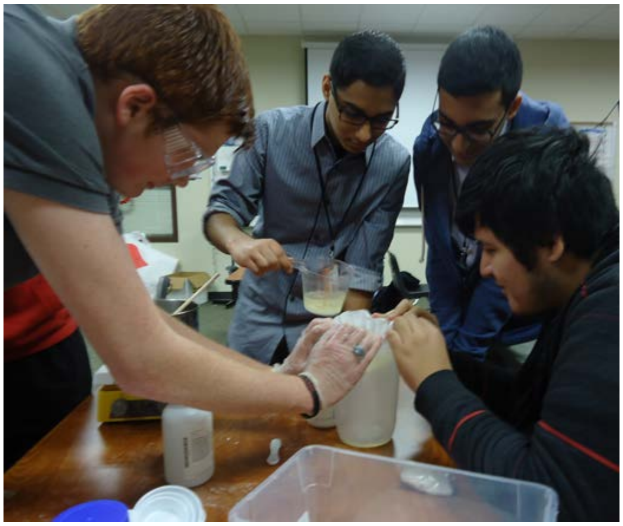

Figure 4. Students making the crystals.

Evaluation

This lesson was implemented in November 2014 in a high school Engineering Design and Development course with 45 students. Of these, six participated in the evaluation. Pre and post tests were conducted to evaluate what they learned, and they also rated various aspects of their lesson and lab learning experience using a 7 point Likert scale (1=strongly disagree; 7=strongly agree).

Student	Pre-Test	Post-Test
A	25	80
B	25	40
C	50	30
D	25	90
E	25	60
F	25	80
Average	29.16	63.33

A paired t-test suggests that the difference in the average score before and after the lesson is significant, meaning there was a learning gain. In addition, the mean responses to the opinion survey questions are shown in Figure 5 below. Student ratings were positive for all items. In general, students felt the Piezoelectric lab and instructional materials helped them to learn more about Piezoelectric and that the hands-on experience helped them to visualize the process. They felt that using Piezoelectric was useful and wanted to have more tools like it available.

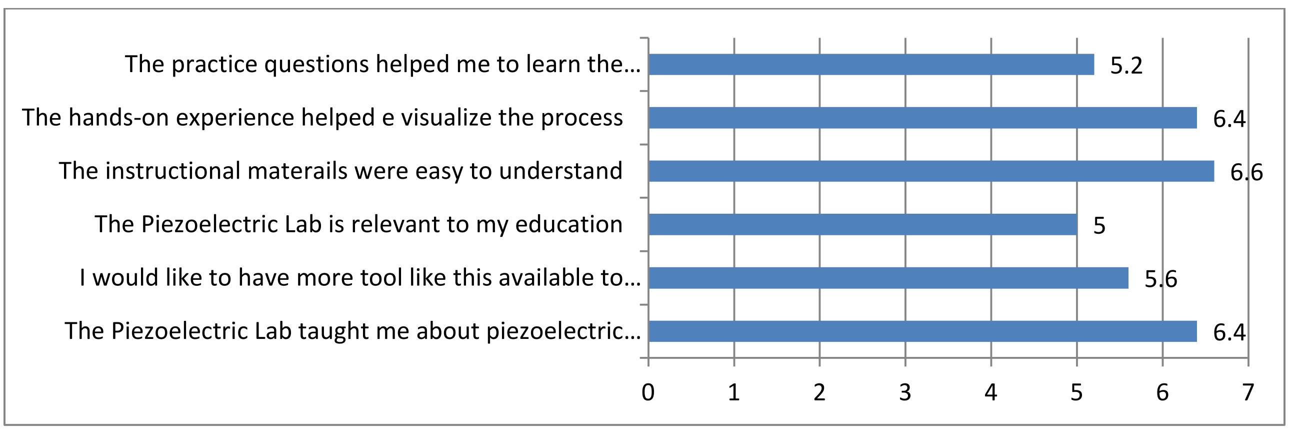

Figure 5. Results from Opinion Survey

Summary

This paper described the design, construction, and evaluation of an instructional module for K-12 science and engineering students on energy harvesting using piezoelectric crystals. The module was used in three engineering classes. Students worked in teams to prepare crystals and successfully tested them. An evaluation of the module indicated that a high level of learning was achieved. In addition, the students all enjoyed the hands on experience.

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