Resistance Behaviour of Quantum Tunneling Composite (QTC) Pill for Tactile Sensor Application

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ABSTRACT

A metal polymer composite known as Quantum Tunneling Composite (QTC) has ability of turning into a remarkable material for new era sensor. This is considering QTC material flexible, soft and has extraordinary electrical properties. Its resistance changes during compressing; thus, changing the way it conducts. This paper proposes two methods which are conducted based on the sensitivity of the QTC pill. The piezoresistive experimental test was performed by sandwich and side by side contact arrangement to determine the QTC pill resistivity characteristics and suitability tactile sensor. The result shows that the QTC pill resistance of sandwich and side by side contact arrangement values dramatically drop at the beginning, and then start stabilized at point 4.903N and 5.884N respectively. From the exponential curve graph obtained through resistance versus force (R vs. F) investigation, it shows QTC pill is a good insulator as well as a good conductor when compressed. Based on this investigation, QTC pill provides benefit in developing tactile sensor with its capability to increase the conductivity of the metal polymer composite under mechanical deformations until a certain force.

Keywords: *Quantum Tunneling Composite (QTC) Pill, tactile sensor, sensitivity, piezoresistive.*

Introduction

The scientist, David Lussey has discovered new material known as Quantum Tunneling Composite (QTC) made from small metal particles (nickel) mixed

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into elastomeric material such as silicon rubber in 1997 [1, 2]. This material is made from metal particles (nickel) embedded in a polymer. It also works as a sensor or switch when pressure is applied. This technology can be used for all kind applications or switching applications. Due to its flexibility, it is convenient for a large range of applications and has a great freedom of shape. For instance, Microsoft implemented the technology in a pressure sensitive keyboard used for a new experience in gaming and spell checking software. It is also used in robot arms that can now feel how firm they have to hold a certain product. On the other hand, QTC developed as tactile sensors for robotic hands by NASA.

In recent decades, the advances in technology allow creation of variable tactile sensor from variable of material and become an essential to human life. Therefore, it is encouraged to developing tactile sensor which is simple, inexpensive and small sensors with low power consumption. Conventional sensor systems depend on mechanical transformations to convert changes in the environment into electrical signals. Growths in materials and manufacturing technologies extended to microelectromechanical systems (MEMS) are acknowledge the development of new sensor systems to bring these newer requirements [3]. Hence, it is essential to study a new alternative material that could be applied as a tactile sensor.

Nevertheless, the tactile sensor is a device that measures information emerges from physical interaction with its environment. In addition, it is becomes an essential part especially in tactile device design. According to Lee and Nicholls [4], a tactile sensor can be defined as "a device or system that can measure a given property of an object or contact event through physical contact between the sensor and the object". Several of vital characteristics of tactile sensors are contact force [4], surface area, and surface conditions [5-6]. Tactile sensor technologies are categorized by the transduction method used to transform stimuli from the external environment in a suitable form for an intelligent system. Therefore, the transduction methods have been used to improve the tactile sensing capability of devices. The main groups of transduction method for tactile sensing technologies developed by this time were piezoelectric, optical, magnetic, capacitive and piezoresistive [7].

QTC is a metal polymer composite that can be grouped into a category piezoresistive transduction method. The piezoresistive contrast to the piezoelectric due to piezoresistive effect causes a change only in electrical resistance, not in electric potential [8]. Instead of, piezoresistive effect is a measures changes in the electrical resistivity (resistance) of a contact when mechanical strain (force) is applied. The major benefit offered by QTC material in developing sensing systems with its capability to increase the conductivity of the composite under all mechanical deformations [9].

Even though this composite material emerges in sheet, ink, and cable form for different practical use, pill form of QTC material is chosen in this study which is better in analyzing both mechanical and electrical phenomena [10, 11]. In addition, it needs more exploration and investigation in order to determine their potential as a tactile sensor.

The Material Working Principle

The working principle of QTC material differs from conventional material because the strange phenomenon which called "quantum tunnelling" takes place when force applied to it. This material is made of spiky conductive nanoparticles suspended in a binder that isolates them from one another.Using this principle, it able change the barrier potential through applied force and effectively change the materials resistance. When no force is applied, the material behaved like an insulator with resistance of 10^{14} Ω, but it will turn into a conductor when force is applied with resistance less than 1 Ω [2]. Detailed working principle of this material will explain in force conduction-level. Figure 1 shows the QTC material appears in pills form.

Figure 1: Quantum Tunneling Composite (QTC) in pills form [1]

A QTC pills are tiny pieces of the material manufactured in a few millimeters (mm) across and 1 mm thick. The graph in Figure 2 shows how material changes it resistance based on changes in applied force. When the more force is applied to it, the less resistance occurs.

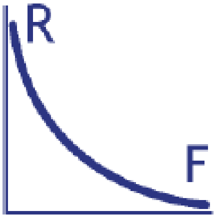

Figure 2: The graph resistance (R) vs. force (F) [1]

Figure 3 shows the force conduction-level of QTC pill. In a state of rest, electricity cannot flow through the QTC pill material due to the metal particles is not in contact and it acts as an insulator. However, when the high force is applied to it, the tips of the spikes metal particles move closer together and a quantum tunnelling effect occurs that enable a current flow.

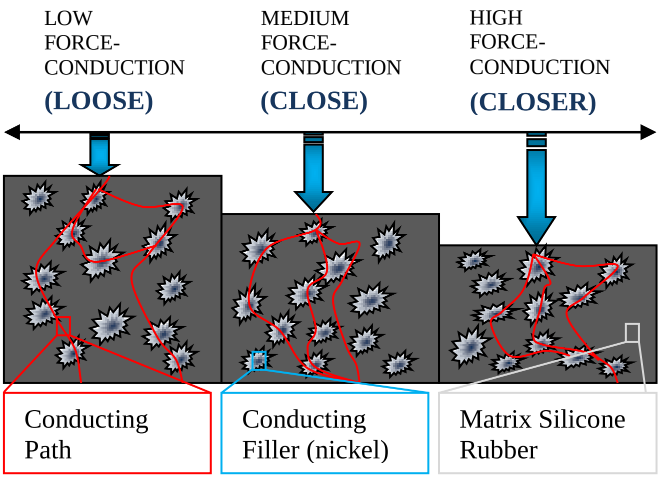

Figure 3: Force-conduction level of QTC pill

Although the metal particles are compressed closer together, it's actually does not touch each other. The small metal particles known as nickel submerging in material always remain separated even when the material is deformed. At the same time, the process is known as "quantum tunnelling" occur when the metal particles closer together for electrons "tunnel" through the material from one metal particle to another other. The high charge densities of electricity generates onto the tips of the spikes that enables a current to flow.

Figure 4 describe the information processes between force, QTC pill and signal where force is moved proportionately into signal.

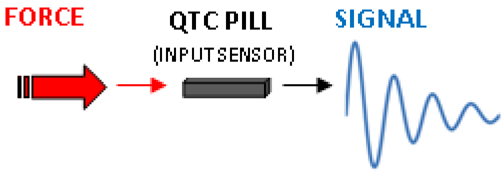

Figure 4: The information process force into signal

As explained previously, the displacement of the metal filler particles caused applied force to the material. The spike of metal particles grab into each other when pressed closer together and allowing an electrical signal to pass. The resistance is the output which influences the voltage for general operating lower than 40V. Thus, the voltage is an indicator for the total of force that is applied. In addition, QTC material with a small piece of 3.6mm x 3.6mm and 1mm thickness be able pass a current of up to 10 amps when pressed.

The Piezoresistive Test

Since the QTC pill reported in piezoresistive transduction method category, thus it is vital to investigate working principle and determine resistance behaviour in the material. The advantages of piezoresistive are good overload tolerance, low cost and ability for small fabrication [9]. QTC has been considered as flexible material and exhibits outstanding electrical properties which have the potential of becoming excellent materials for new era sensors. Hence, a tiny pill measuring 3.6mm square and 1mm thick of QTC material is chosen due to it is better in analyzing both mechanical and electrical phenomena [10]. Thereby, analyzing mechanical is in term of compress force, while analyzing electrical is in term of resistance, current and voltage.

To achieve the performance and suitability of QTC pill as tactile sensors, the experimental setups for piezoresistive test was established. Based on inspired from other researchers [12, 13] have done previously, there are two vital contact arrangements which are sandwich and side-by-side. The sandwich contact arrangement is shown in Figure 5, while the side-by-side contact arrangement is shown in Figure 6 assembled for this study. To investigate the behaviour of resistance versus applied force (R vs. F), the QTC pill was placing between 75-µm thick coopers (Cu) sheet and wrapped them with adhesive tape. The width of Cu sheet should not larger than QTC pill to overcome short circuit occur.

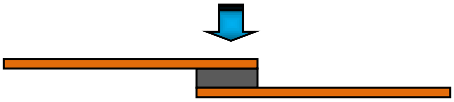

Figure 5: Sandwich contact arrangement

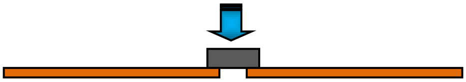

Figure 6: Side-by-side contact arrangement

The experimental setups are described in Table 1 which contains contact arrangements, parameter and voltage supply for piezoresistive test.

Table 1: Experimental Setups for the Piezoresistive Test

Experimental setup		
Contact Arrangements	*Parameter*	*Voltage Supply*
Sandwich	Force applied to QTC pill by placing directly between contact Cu surfaces.	5V
Side-by-side	Force applied to QTC pills by placing with 0.25mm separation gap between contact Cu surfaces.	5V

All of the setups in Figure 7 and Figure 8 were measured using the two main devices in this study. They are “Mastech MY-68” digital multimeter and “Mark10 Series 5” digital force gauge. A digital multimeter is an electronic measuring instrument to measure resistance; on the other hand the digital force gauge is used to measure compression force. Slotted mass not selected in this study on account of the accurate values that can be finely modulated by using digital force gauge. Figure 7 shows the illustrated arrangement (sandwich contact arrangement) of circuit connection, while Figure 8 shows actual arrangement.

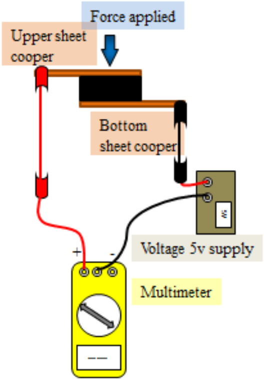

Figure 7: Illustrate arrangement of assembly

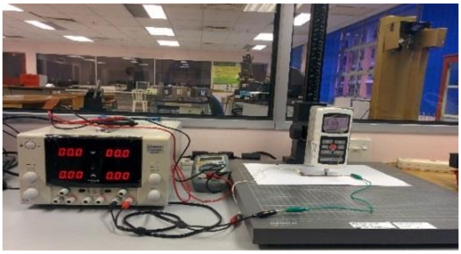

Figure 8: Actual arrangement assemble

These circuit connection are prepared for sandwich and side-by-side contact arrangement to determine the QTC pill resistance behaviour in a standard way. Afterward, the setup was measured in the range force between 0N (0gF) and 9.81N (1000gF) using digital force gauge. The multimeter is then connected to the upper and bottom Cu sheet with alligator clips as shown in figure above. It is then lightly pressed on the digital force gauge, and pressure is increased. Read off the load number on the digital force gauge and measure the resistance at the same time. For uniformity, conduct this experiment in a single run and gently rise the force. Take at least three measurements and plot the data recorded in Microsoft Excel. Repeat this method for the side-by-side contact arrangement and compare the results.

Result and Discussion

The experiment was conducted using two types of contact arrangements, composed of sandwich and side-by-side. The QTC pill resistance measured in the range force between 0N and 9.81N. Figure 9 and Figure 10 represent the R vs. F relationship is an exponential.

Previously was explained, the QTC material will be a perfect insulator in zero compression, while resistance will be limitless up to 1014 Ω. It can be seen that the resistance of sandwich (Figure 9) and side by side (Figure 10) contact arrangement values dramatically drop and curve profiles began to drop stably at point 4.903N (500gF) and 5.884N (600gF) respectively. Even though, in theory resistance produce exponential curve when force is applied to material, it actually difficult to achieve in practically. The result sandwich contact arrangement recorded at 0.981N the resistance value is 7.58Ω, while the maximum value of force 9.81N results in resistance of 1.02Ω. Meanwhile, the results of side-by-side contact arrangement with gap of 0.25mm show resistance is 7.33Ω at force of 0.981N compared to force of 9.81N, which results recorded is 0.89Ω.

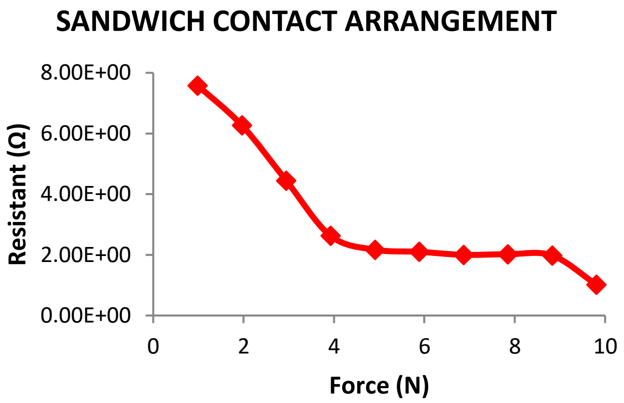

Figure 9: Sandwich contact arrangement of QTC pill change in R vs. F

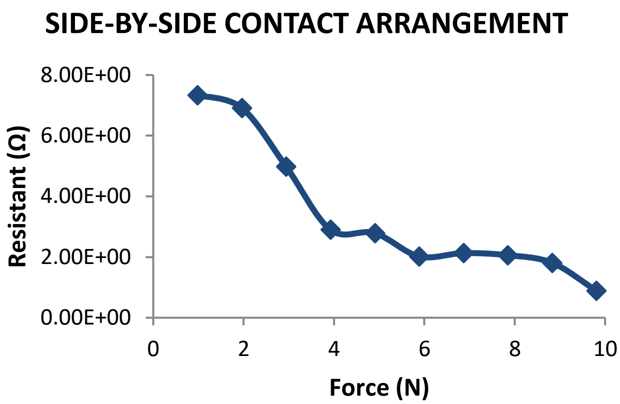

Figure 10: Side by side contact arrangement of QTC pill change in R vs. F

Usually, the characteristic of conventional material requires a linear; however the QTC pill resistance decreases exponentially upon compression. It represent the more force is applied will produce the less resistance reading. Obviously, the material is very sensitive towards existence of force. In addition, this result support with a quantum tunnelling hypothesis; "if the deformation of the gaps between the metal particles is linear, the exponential decay of the electron wave function should lead to an exponentially higher probability of tunnelling". This is considering the effect presented by QTC pill is strong and extremely responsive to deformation existence of nickels.

Conclusion

This study agree with the statement QTC is a material made from particles of a metal (nickel) embedded in an elastomeric material when the results presented it resistance changes dramatically when it is compressed. The outcome demonstrates the QTC pill is a perfect insulator as well as an extremely good conductor. The detailed analysis and findings of this paper indicated that the sandwiches contact arrangement data is more stabilized compared to side-by-side contact arrangement due to the smooth result plotting. Furthermore, from the study of R vs. F shows that QTC pill is different from other piezoresistive materials which exponential graph was obtained. This indicates that QTC pill is very sensitive and suitable candidate for tactile sensor applications. This is reasonable with the hypothesis of quantum tunneling charge carrying inside the polymer "assisted" quantum tunneling.

In a nutshell, this material has unique resistance response changing from off “insulator” to on “conductor” which has potential applications in sensitive electronic devices. Besides, QTC material is multipurpose, both electrically and mechanically which its sensitivity can be altered. It is hoped that piezoresistive test suggested in this study will add knowledge to other researchers to study the same material.

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