ESD Susceptibility of High Gauge Factor Thick Film Piezoresistors

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Abstract

CTS began manufacturing pointing devices in 1994 for use as cursor controls, mounted in the keyboards of notebook computers. While completed keyboards were robust against ESD, many precautions were required during manufacture and assembly to protect against the effects of ESD. While these ESD "protective" controls were effective in controlling ESD, they did not eliminate the ESD susceptibility of the pointing sticks. ESD Susceptibility of high gauge factor thick film resistors was investigated. The thick film resistor processing and the resistor design parameters were studied. Improvements in the thick film resistor paste and strain gauge resistor design have produced pointing sticks capable of withstanding an ESD of 20KV.

Key words: Gauge factor, Joy stick, Piezoresistors, Pointing stick, Thick film resistor

Introduction

Piezoresistivity is a reversible phenomenon wherein under the influence of an externally applied stress a resistor exhibits a change in resistance. This change in resistance persists as long as the applied stress prevails. This fractional change in resistance is proportional to the applied strain. The constant of proportionality is defined as the Gauge Factor (GF).

Piezoresistive materials used for strain gauge applications are classified into three groups: thin metal films, thick film resistors and semiconductors. Over the past two decades several commercial as well as potential applications of thick film strain gauges have been studied. Device performance characteristics with advantages and limitations of such applications have been reported by Stecher et al. [1], Dell'Acqua [2], Satoh et al.[3] and Pudenziati et al. [4]. The thick film strain gauges are an excellent compromise between the performance characteristics of the other two types of strain gauges, thin metal films and semiconductors. Also, the in-line print and fire thick film manufacturing is simple, economical and reliable. High GF thick film resistors are used in a wide variety of low cost, high reliability strain gauge and sensor applications. These applications include acceleration, force, pressure, weight, computer joy stick or pointing stick. The high gauge factor thick film resistors, ESL #3414-A and ESL #3414-B have GF in the 14 to 20 range for sheet resistance in the 1kΩ/sq to 10kΩ/sq range [5] and exhibit low temperature dependence: Temperature Coefficient of Resistance (TCR) less than 100ppm/^{o}C and Temperature Coefficient of Gauge Factor (TCGF) less than 500ppm/^{o}C.

CTS corporation began manufacturing pointing stick devices in 1994 for use as cursor control. The device is mounted in the keyboards of notebook computers. This strain gauge device consists of ESL high GF thick film resistors in a bridge network. The resistors are printed and fired on a ceramic cantilever beam. The resistance bridge is in a balanced state in the standby mode with no external force exerted on the pointing stick. Flexing of the pointing stick induces a strain in the resistance bridge causing an imbalance in the bridge network. This imbalance results in a proportional bridge output signal. An algorithm converts this bridge output into a corresponding two dimensional motion of the pointer on the monitor screen.

During the developmental stage of this device a sudden permanent change in the device standby mode was observed. This change was due to a permanent negative shift in the resistance of the device. The cause for this change was determined to be electrostatic discharge (ESD). ESD was measured at both, CTS and the keyboard manufacturers, to determine the amount of ESD generated in a typical keyboard assembly operation. Maximum ESD was typically in the range of 8 to 14kV. An ESD of 14kV produced about a 4% negative resistance change in the pointing stick device.

This study was conducted to understand the effect of ESD on the high GF thick film resistor strain gauges. The goal was to use these findings to minimize the ESD susceptibility of the pointing stick device thereby enhancing its reliability. The preliminary observations indicated that the major contributors towards device ESD susceptibility were the resistor paste and the strain gauge resistor design. This study involved optimization of these two factors so as to minimize the device ESD susceptibility. Based on preliminary engineering studies and product analysis of the pointing stick device, CTS established a 0.25% maximum resistance change (ΔR) after 20kV ESD as the design and construction target. ESL was to optimize the thick film resistor paste to meet this ESD _R target. Also, any process and design variations had to be such that the resistors would still have a sufficiently high GF to maintain the required level of strain sensitivity for a pointing stick device.

Experimental

The effect of ESD on high GF thick film resistors was investigated. A thick film resistor paste consists of conductive and non-conductive materials particulate suspended in an organic fluid. During the typical high temperature (825^{o}C or higher) processing of thick film resistors the conductive particulate form a chain network in the non-conductive material matrix. The electrical as well as mechanical performance characteristics of such a resistor depend on several factors, dominant of which are the material characteristics, high temperature resistor firing profile and the resistor part design. The effect of these three factors on the ESD sensitivity of ESL #3414-B high GF thick film resistors was evaluated.

The test parts were prepared on alumina substrates. Prefired palladium-silver conductor, ESL #9635-A, was used to terminate the resistor. The conductor and the resistor were fired in a continuous belt furnace.

Test parts with five different resistor geometries or designs were investigated (resistor design #s 1, 2, 3, 4, and 5). This enabled us to vary the ESD voltage gradient across the resistor. This variation was thus independent of the actual voltage used in the ESD test. The change in resistance (ΔR) due to the applied high voltage pulse was a measure of the ESD sensitivity of the resistor. The higher the magnitude of _R, the greater the ESD sensitivity or susceptibility.

Using several different proprietary manufacturing processes five lots (A, B, C, D and E) of the thick film resistor paste were prepared. All of these lots had the same chemistry. The process variables evaluated resulted in materials lots with different physical and electrical properties. These pastes were fired using a typical thick film resistor firing profile: 10 minutes of soak time at 860^{o}C peak firing temperature, total profile time of 30 minutes. The longitudinal GF was in the range 17 (for paste lot E) to 22 (for paste lot A). These five pastes were evaluated to investigate the effect of resistor materials properties on the ESD sensitivity (ΔR) of the resistor. The test resistor designs used were #s 1, 2, and 3. The ESD test voltages ranged from 6kV to 10kV. The ESD test equipment used was IMCS Model 2400C [6].

The resistor paste lot that exhibited the least ESD sensitivity (lot E) in the above tests was analyzed to optimize both, the paste manufacturing process and the strain gauge resistor design. The strain gauge designs were to meet the expected package size requirements as well as the 20kV ESD ΔR requirement. Proof product was manufactured with existing manufacturing equipment and operating procedures. The product was tested for ESD robustness as well as pointing stick device functionality.

The resistor paste lot that exhibited the least ESD sensitivity in the above tests (lot E) was selected to study the effect of high temperature resistor firing profile on ESD sensitivity. The thick film resistor test parts were processed at three different peak firing temperatures (825°C, 850°C and 875°C) and three different soak times (5, 10 and 15 minutes) at the peak firing temperature. The test resistor designs used were #s 4 and 5. The ESD test voltage used was 2kV. Figure 1 shows the schematic of the ESD test equipment used.

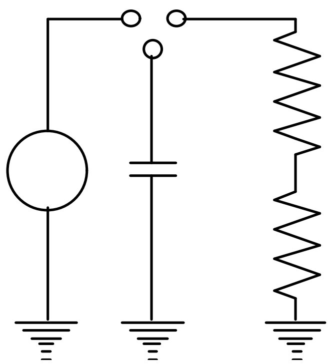

Figure 1: Schematic of ESD Pulse Tester

Results and Discussion

The effect of the resistor materials properties was investigated on five different lots of resistor paste using three different resistor designs (design #s 1, 2, and 3). The ESD _R data illustrated in figure 2 shows the effect of a single 6kV ESD pulse on the three different resistor designs. With resistor design #1, paste lot A with GF = 22 is very sensitive to ESD whereas paste lot E with GF = 17 is relatively insensitive to ESD. At this particular ESD voltage gradient (resistor design #1) the ESD ΔR is very sensitive to the paste manufacturing process. This type of process dependent paste sensitivity is minimal at ESD voltage gradients obtained with resistor design #3. The ESD sensitivity for resistor design #2 is a compromise between that for resistor design #s 1 and 3. Figure 3 illustrates the relationship between the ESD voltage gradient and the absolute resistance change | -ΔR | . The data indicates that a strong relationship exists between the ESD sensitivity and the ESD voltage gradient. The ESD sensitivity of the strain gauge and the pointing stick device is reduced as the ESD voltage gradient is reduced.

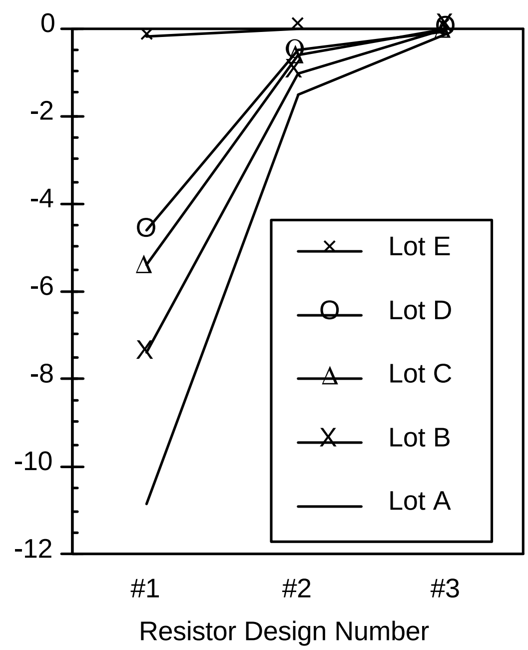

Figure 2: ESD ΔR vs. Resistor Design, Resistor Paste Lots A, B, C, D and E, Single 6kV ESD Pulse

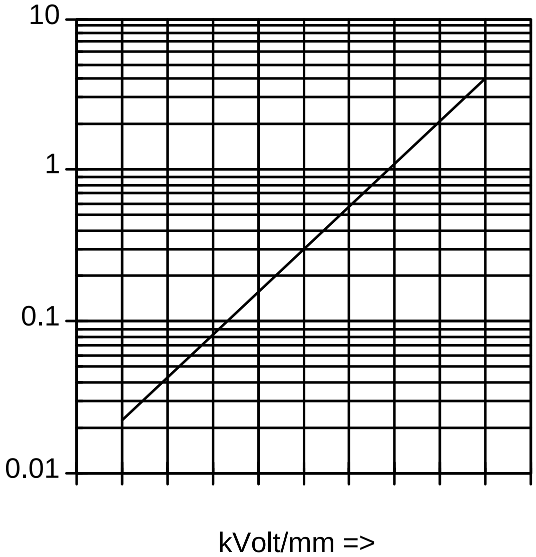

Figure 3: Expected ESD Performance of Pointing Stick Device
Resistance Change vs. ESD Voltage Gradient

The above observations were analyzed by CTS to establish 0.25% maximum absolute resistance change after 20kV ESD as the pointing stick device design and construction requirement. The ESD _R data was analyzed to optimize the strain gauge resistor design. Based on this optimized design, prototype pointing stick devices were manufactured from resistor paste lot E. These devices met the required strain sensitivity, performance characteristics and package size. Figure 4 illustrates the ESD performance of these devices. The results indicate that the design meets the ESD requirements and exceeds the expectations. The device is ESD robust without sacrificing functionality.

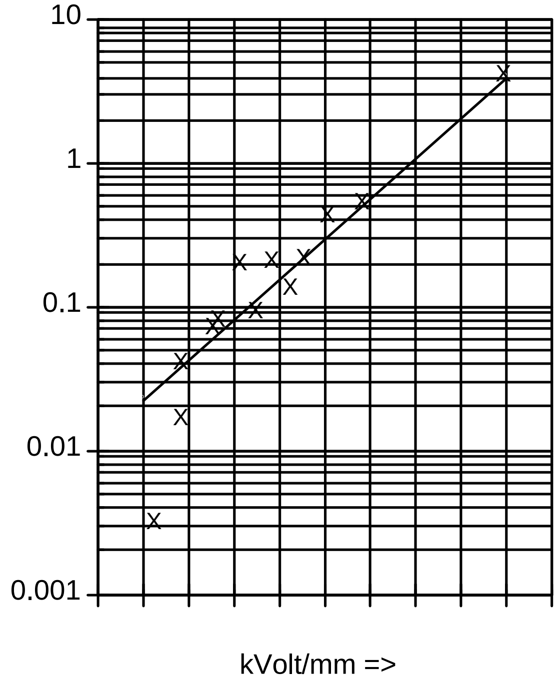

Figure 4: Actual ESD Performance of Pointing Stick Devices
Resistance Change vs. ESD Voltage Gradient

The paste lot E was selected for studying the effect of resistor firing profile on ESD sensitivity. The ESD sensitivity was evaluated by applying three 2kV pulses. Figures 5 and 6 illustrate these test results. The resistor design #s 4 and 5 were used for this test. The data shows that resistor firing profiles employing peak firing temperatures of 850°C and higher, and soak times of 10 minutes and longer, are preferred.

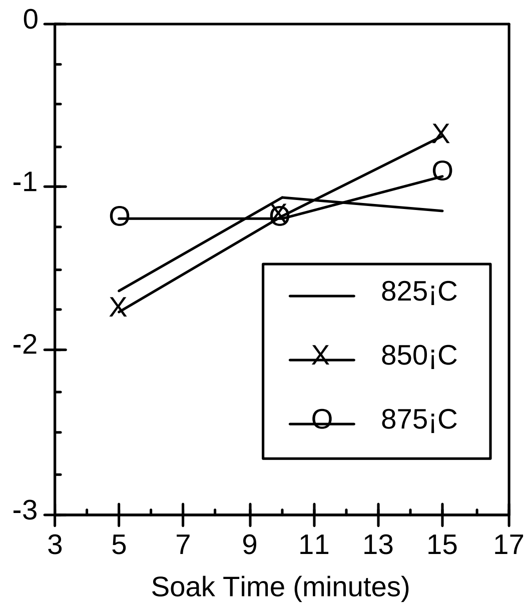

Figure 5: ESD ΔR vs. Resistor Firing Profile, Resistor Paste Lot E, Resistor Design #4

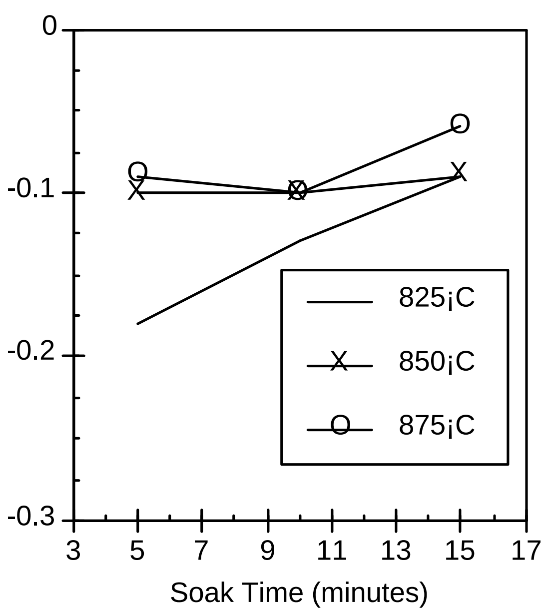

Figure 6: ESD _R vs. Resistor Firing Profile, Resistor Paste Lot E, Resistor Design #5

The characteristics of a semiconductor are determined by its electron energy levels, e.g. the Fermi level and the semiconductor band gap. The relative levels of such electron energy bands are influenced and altered by application of an external stress [7]. This property gives rise to the piezoresistive phenomenon observed in semiconductor strain gauges with GFs of 50 and higher magnitude. ESD destroys the structure of semiconductor electron energy levels and leads to device failure.

The microstructure development and charge transport in thick film resistors has been a subject for numerous studies over the past three decades. A thick film resistor is a heterogeneous system. The type of firing profile used to process such resistors results in a metastable microstructure of chains of conductive particulate extending across the length of the resistor dispersed in a non-conductive matrix. The typical conductive phases are precious metal oxides. The non-conductive matrix is primarily a glass. At the peak firing temperature the conductive phase exhibits some solubility in the molten glass phase. This results in sintered and non sintered contacts between adjacent conductive particles. Thus, the thick film resistor can be characterized by numerous metallic and semiconducting clusters or zones forming a series-parallel conductive network across the length of the resistor. Based on this typical microstructure, Vest [8] proposed a model for sheet resistivity of thick film resistors.

Theories and models explaining electrical properties of heterogeneous systems date back to 19th century and such giants as Avogadro, Faraday and Maxwell. Landauer [9] published a historical review of the subject. Chaikovskii [10], in his review of proposed models for charge transport in thick film resistors, has presented an analysis of strain sensitivity in thick film resistors. Abe and Taketa [11] proposed that in high GF thick film resistors the contribution of semiconducting zones is relatively higher than that in conventional thick film resistors (with GF of 3 to 8 at 10kΩ/sq) used for hybrid applications. The materials system and chemical composition of the resistor influences its GF. Also, for a given resistor system, the GF increases as the sheet resistance increases. These observations can also be explained on the basis of the role played by the semiconducting zones in the resistor microstructure. The semiconducting zones contribute to increased sensitivity and to increasing non-ohmic properties. Such a hypothesis can explain why resistors with GFs of 15 and higher are more susceptible to ESD when compared to the conventional resistors.

Summary

The ESD susceptibility of high gauge factor thick film piezoresistors is a function of the resistor materials properties, gauge factor, the thick film resistor firing profile and the strain gauge resistor design.

The ESL #3414-B resistors have gauge factors of 17 to 18. One of the commercial applications for these strain gauges is a pointing stick device integrated in the computer keyboard. The reliability of this device was enhanced by optimizing the resistor materials and the strain gauge resistor design.

A relationship between ESD sensitivity and ESD voltage gradient was established and verified. The key materials and processes in the resistor paste system were identified and optimized. The device resistor design was optimized to produce less than 0.25% absolute resistance change after 20kV ESD.

Acknowledgments

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