Photolithographic Processes for Creating a Proximity Sensor in Low Temperature Co-Fired Ceramic Tapes

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Abstract

This paper describes two photolithographic processes for patterning Low Temperature Co-Fired Ceramic (LTCC) tapes. The processes involve the use of two types of LTCC tape. In one case photoformable tape is used, and in the other, DuPont 951® tape coupled with DuPont Riston® 9015, a dry photoresist, is used. Although a full 8-layer sensor was not completed using either method, single spirals were fabricated and compared to past sensors fabricated using other methods. The parasitic resistance of a single spiral fabricated by the photolithographic methods was 20% of that found in spirals fabricated using screen-printing. The process steps used in creating the spirals as well as important parameters are discussed, and suggestions for improvements in the process are made.

1. Introduction

Proximity sensors based in silicon have been utilized for many years in a host of different applications. Their usefulness is limited, however, because their responsiveness drops significantly at a temperature of approximately 70°C, when the silicon shows its intrinsic characteristics. Thus for high-temperature applications, another material must be used. Low Temperature Co-Fired Ceramics (LTCC) are a class of materials that show relatively high mechanical strength, thermal stability, and cost effectiveness, making them the logical choice for these applications. Several methods are currently available for patterning structures in the LTCC tape. Two of the most recently discovered are presented in this paper.

1.1 LTCC

LTCC tape is so named because of several material properties including firing cycle, firing capabilities, and composition. It is considered to be low temperature because the tape is fired at a temperature below 1000°C. Because the tape and all passive elements that may be embedded in it can be fired at the same time, it is said to be co-fireable. Since the major component of the tape is oxides, it is a ceramic.

Two forms of LTCC tape were used in this project. The first, a photoformable type, is a research material and is thus not commercially available. The composition of this tape is 45% glass, such as PbO and SiO_2; 40% Alumina, $Al_2O_{3;}$ and 15% organic binders [1]. The organics are added to improve the rheology and flexibility of the tape when in the "green" (pre-fired) state. In the photoformable tape, the organic binders are photosensitive and cause the tape to act as a negative resist. The other form of tape used is DuPont's commercially available 951® LTCC tape in which the organics are not photosensitive.

The tape is soft and easily deformed when in the green state. Because of this, it is easy to mechanically laminate multiple layers of tape by placing them in a press and subjecting them to pressure. This lamination, usually done at 85°C and 4000 psi for 15 minutes, creates multi-layer structures that can form a complex system of vias and elements within a single sample[2]. This formation of 3D structures is necessary to create a proximity sensor using flat coils, as will be discussed later.

Once all structures are in place, the tape is ready to be fired. The firing cycle is summarized in Figure 1 and is also described below.

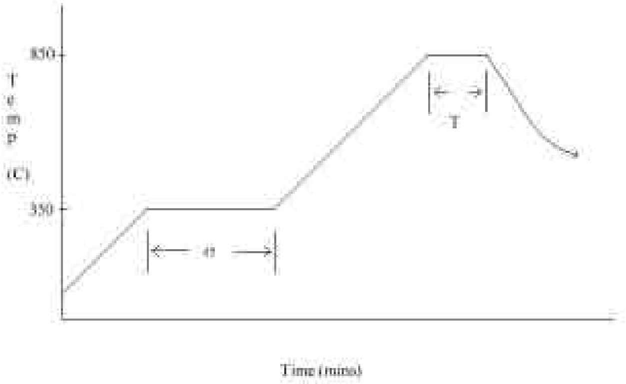


Figure 1: LTCC Firing Cycle.

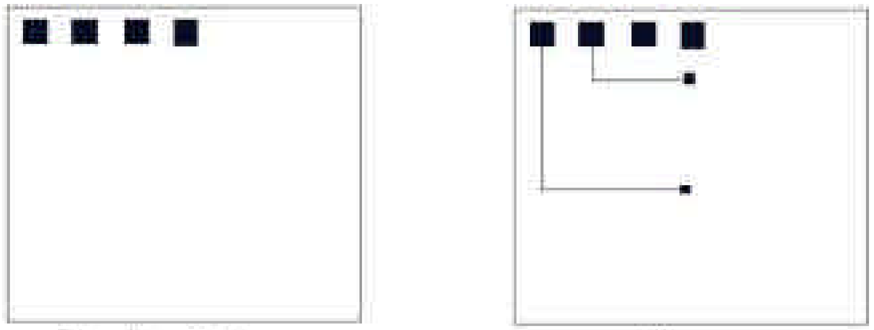
The tape is first brought from room temperature, approximately 22°C, to 350°C on a 10°C/minute ramp. It stays at 350°C for 45 minutes and is then brought to 850°C on a 10°C/minute ramp. At 350°C, all of the organic material in the tape burns off. Had the tape been brought directly to 850°C, these organics would have formed carbonates, which degrade most of its properties; thus it is important that they be completely burned off.

The tape is kept at 850°C, T in Figure 1 above, for either 2 or 30 minutes depending on whether the desired result is a fully- or semi-sintered sample. The glass transition temperature of the glasses in the tape is around 810°C; at 850°C, this glass begins to flow and surround the grains of ceramic, joining them together. If the tape is left at 850°C for 2 minutes, the flow of the glass will have just started and the grains of ceramic will be loosely attached. However, if the tape is left at 850°C for 30 minutes, the glass will have fully flowed and surrounded the grains, bonding the nearby grains strongly. Both semi- and fully-sintered samples were utilized at various stages in this project, and the type of firing cycle employed with each sample will be noted at the appropriate time. After 30 minutes at 850°C, the furnace is turned off and the tape is allowed to cool.

During the firing process, the tape shrinks 12.7 ± 0.2% in the X-Y direction and 15 ± 0.5% in the Z direction as a result of the loss of the organic material in the tape and the flow of the glass bringing the grains closer together [1]. This shrinkage needs to be compensated for when designing structures that depend on different layers lining up correctly, otherwise electrical continuity may not be achieved.

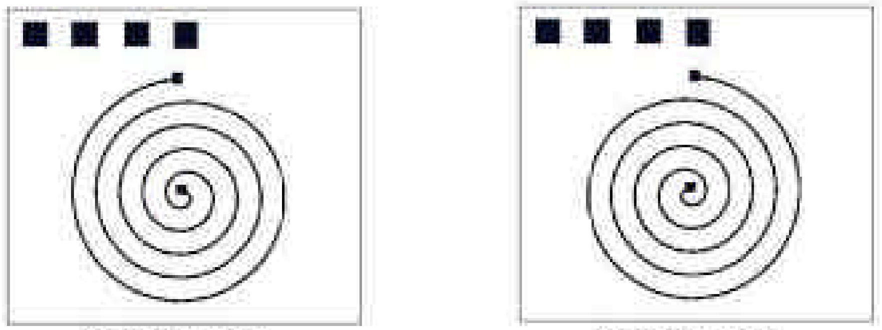
1.2 Proximity Sensor

To create the proximity sensor, several layers of tape had to be patterned, filled with a conductive paste, and laminated together. Figure 2 shows the patterns used in creating the sensor.



Bonding Pads

Vias



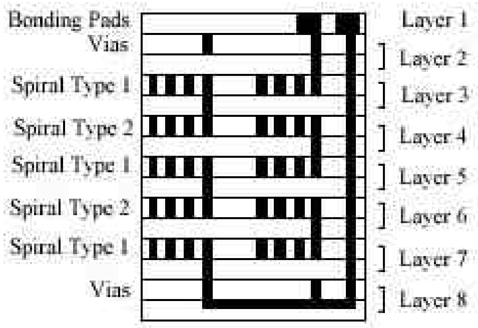
Spiral Type 1

Spiral Type 2

Figure 2: The four different masks used to pattern the tape.

The basic building blocks of the sensor are the two types of spiral. The black areas in the figure were removed from the tape using one of the methods that will be discussed later. Then, a silver-palladium (Ag-Pd) paste was spread into the cavities. Since the paste has an inherent resistivity, the spirals each had a resistance value. Each spiral also had an inductance value due to the spiral design, as well as a parasitic capacitance, because each line of conductor was separated from the others by an insulator, which is the definition of capacitance. Thus in each spiral there was an RLC circuit, and when multiple layers were laminated on top of each other, these values grew.

Once these layers had been created, they were combined to form the full sensor. Figure 3 shows how these layers were combined. Two different orientations were needed for the spiral in order to achieve any inductance. Inductance is created when a current passes through a wire, forming a magnetic field around that wire that follows the right-hand rule. When these magnetic fields overlap, they can combine either constructively or destructively. Since these layers were combined either at the center or top of the spiral, if only one orientation was used the current in one layer would follow the opposite path of the current in the layer above. This would completely cancel out the magnetic field and reduce the inductance value to zero. When two-layer sensors were created using two spirals that had the same orientation, this is exactly what occurred. Thus it was necessary to alternate the orientation of the spirals.



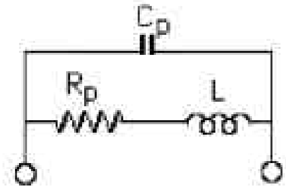


Figure 4: Equivalent circuit of the sensor

Figure 3: Layout used to combine the layers into the sensor.

A proximity sensor works on the principles of resonance and inductance coupling. All RLC circuits have a frequency at which their output is a maximum. As the frequency increases, the impedance of the inductor increases while the impedance of the capacitor falls. At the resonant frequency, the combined impedance of the system is at a minimum. Figure 4 shows the equivalent circuit of the sensor. For this circuit configuration, the formula used for determining the resonant frequency, f_0, can be approximated as:

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \qquad (1)$$

This value of the resonant frequency is valid only if there are no ferromagnetic materials or metals nearby. If there are, the magnetic field lines from the sensor enter into the metal and interact with it. This interaction is known as inductance coupling and changes the value of L in formula (1). A change in the inductance value shifts the resonant frequency. This shift of resonant frequency is what the proximity sensor measures. It can be used to count the number of metallic elements that pass by it or, if it is calibrated correctly, it can be used to determine how far away a metallic object is.

1.3 Photolithography

Traditional patterning methods of LTCC tape include punching and machining. These methods have a major drawback: they are strictly serial processes, and no more than one sample can be patterned at a time. Batch processing is inherently faster than serial processing because it offers the ability to pattern multiple samples at one time. One method available for batch processing is photolithography.

Photolithography, from the Greek words *lithos* (stone) and *graphien* (to write), is an old technology that has been used in many industries, from photography to integrated circuit fabrication. The earliest known example of photolithography dates back to 1827 when a Parisian engraver named Lemaitre etched a copy of an *Engraving of Cardinal d'Amboise* [3].

Photolithography today uses one of two methods, a positive or negative resist. The term resist is derived from the material's ability to protect the area under the pattern from processing. In both cases, light from an ultraviolet source shines on the resist. Positive and negative resists are distinguished by the subsequent reaction. In a positive resist, the area exposed to the light undergoes a reaction to form an alkali-soluble product [4]. The unexposed area is not soluble in the alkali solution that is used as the developer. In a negative resist, the area exposed to the light becomes strengthened either by cross-linking or polymerization. Thus it is less likely to be washed away when subjected to a developing solution. This difference is summarized in Figure 5.

Figure 5: Positive v. Negative resists. The dark area is covered by the mask and thus not exposed to the UV light.

Both processes described in this paper utilized negative resists to achieve patterning of the LTCC tape.

Proximity sensors in LTCC have already been fabricated [5]. However, these sensors were fabricated by screen-printing a conductive paste on top of the LTCC substrate. The attempt of this project is to make the LTCC tape an integral part in the pattern and structure of the sensor. The single most important reason for this is the resistance of the spirals. Resistance does not enter into the formula for determining the resonant frequency, so one might erroneously conclude that it is unimportant in the overall design of the sensor. In fact, the resistance is a damping factor, and if it is too large, no resonance might be observed. A large resistance also limits the amount of current that can be put across the sensor, because the current is dissipated through the resistance as heat. If the heat exceeds the limit of the resistor, the resistor might burn, opening up the circuit, as happens when a fuse burns in cars or houses.

The resistance of a wire follows the following formula:

$$R = \frac{\rho L}{A} \qquad (2)$$

Where: ρ is the resistivity (a material constant)
L is the length of the wire
A is the cross-sectional area of the wire

The resistivity, length and cross-sectional width are constant in this case so that comparisons with past sensors of the same design can be made. The only variable that can be altered is the cross-sectional thickness. The thickness of the paste when screen-printed is 15–18 µm. The thickness of a piece of tape when fired is approximately 125 µm. This large change in the cross-sectional thickness should increase the value of A in formula (2), lowering the overall resistance. Figure 6 depicts this difference.

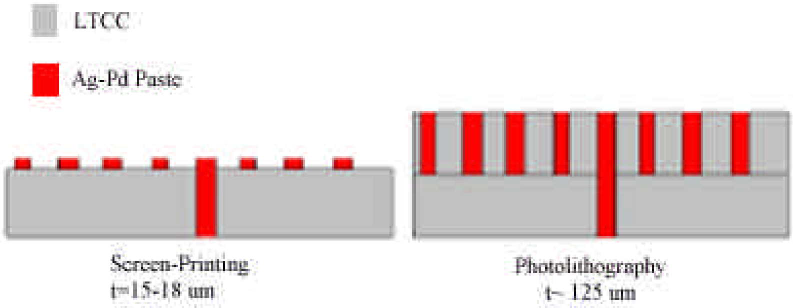


Figure 6: Screen-Printing v. Photolithography for paste thickness

1.4 Riston

One material used in creating the proximity sensor, the photoformable tape, has already been described. It is an inherent unlike DuPont's 951® tape, the other form of LTCC used, which is not photosensitive.

Because the 951® LTCC tape is not photosensitive, a resist must be placed on top of it, and DuPont's Riston® 9015 was used. Most photoresists are liquids that are dropped onto the substrate and spun to achieve an even coating. Riston®, on the other hand, is a dry photoresist and simply needs to be laminated onto the substrate, which is the LTCC in this case.

Riston® comes in sheets and is sandwiched between two materials. On one side of the Riston® is a layer of Mylar^{TM}. This layer protects the resist when it is being handled and also promotes good contact between the mask and the tape when it is exposed to the UV light. The other side of the Riston® is coated with a thermally activated glue, protected by a layer of polyolefin [6].

The layers of Riston® used in patterning the tape are used only as a photoresist, and are thus stripped from the tape following etching.

2. Experimental Results

2.1 Photoformable Tape

The original goal of this project was to build and characterize a proximity sensor in photoformable tape.

2.1.1 Process

Processing photoformable LTCC tapes have been described elsewhere [7]. Unfortunately, not every piece of photoformable tape performed optimally when the procedures described in that work were employed. One possible reason for this is that the photoformable tape is still a research material, and manufacturing procedures have not been finalized. Another possibility is that this material's reliability depends strongly on storage conditions and the amount of time it has spent on the shelf. The steps taken in processing the photoformable tape are summarized in Figure 7.

Figure 7: Processing Procedures for Photoformable Tape.

To conserve the limited amount of tape provided, the minimum amount necessary was used. The masks used to create the proximity sensor require a piece of tape no smaller than 1.5"x1.5". However, all of the vacuum chucks in the lab require a significantly larger piece of material, 3"x3". This problem was solved by mounting each piece of tape on a 3"x3" piece of glass. Because bubbles in the tape could cause poor contact with the mask, exposing unwanted areas to the UV light or developing unwanted areas, a flat contact with the glass was essential. The glass was cleaned with acetone, rinsed with DI water, spun dry, and then placed on a hot plate at 100°C for 5 minutes to insure that the plate was dry. The same procedure was followed on the masks that the tape would be exposed with.

Past proximity sensors that relied on screen-printing did not have to worry about two layers that were laminated on top of each other shorting each other out. But the paste in this sensor was filled into the cavity that went all the way though the tape, so this became a concern. Also, the piece of green tape was extremely fragile after it had been developed, especially when the spiral design had been patterned on it. For these a base layer that was solid all the way through was needed. One method for achieving that layer was to simply laminate two layers together before exposure. Since there is no hydraulic press in the clean room of the lab, this lamination was first done with a roller.

After the glass had been dried, a drop of DI water was placed on it. The first piece of tape was then placed on the drop and spread using a roller. To dry the water and promote good lamination, the plate was then placed back on the hot plate at 100°C for 5 minutes. This layer would later form the base of the two-layer package. Next, another drop of water was placed on top, and another layer of photoformable was rolled into place. This would later be the layer that was exposed to the UV light. The glass plate was once again placed on the hot plate, this time at 50°C for 20 minutes. The lower temperature and longer time promoted good lamination between the layers. Good lamination is desired between the layers, and good lamination is also desired between the bottom layer and the glass, but at some point the tape must be removed from the glass. Unfortunately, a process that achieves both results has not yet been found, and many samples were destroyed because removing the tape from the glass was too difficult.

Once the tape had been laminated onto the glass, it was then ready for exposure. The samples were exposed under a mercury arc lamp at an energy of 100 mJ/cm^2, measured at a wavelength of 365 nm. Contact masking using a regular silicon photolithography mask aligner was utilized. Since the UV lamp provided an intensity of light output and not energy, it was necessary to determine the proper exposure time, since the energy is determined by the following formula:

$$\text{Energy [mJ/cm}^2\text{]} = \text{Intensity [mW/cm}^2\text{]} * \text{Time[s]} \quad (3)$$

After exposure, a 10 minute post-bake at 100°C was necessary to stop the chemical reaction that exposure to the light had started. It was found that it was beneficial to remove the tape from the hot plate and to let it cool completely to room temperature before proceeding. A hold time of about 1 hour was long enough to allow the tape to cool.

The next step in processing the tape is development of the tape. Because the tape acts as a negative resist, all areas not exposed to the UV light would wash away in the developer. The developer used was sodium carbonate, Na_2CO_3, at a temperature ranging between 80°F and 90°F. Optimal development time varied depending on which end of the 10°F spectrum the liquid developer happened to be closest to - 70 seconds if the sodium carbonate was closer to the 80°F end, and 60 seconds if the liquid was closer to 90°F. To insure that all areas of the tape got the same exposure to the developing liquid, the glass plate was placed on a rotating stage under a spray nozzle that sprayed the liquid out at a constant pressure and was attached to an oscillating arm. A diagram of the setup is shown in Figure 8.

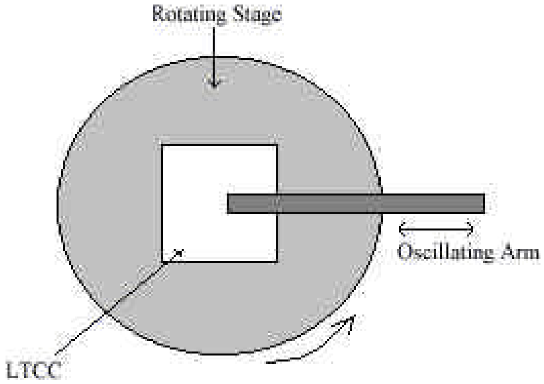


Figure 8: Development SetUp

The development resolution was best when the developer was sprayed at a pressure of 60 psi, rotated at a speed of 35 AU, and oscillated at a speed was 40 AU.

After the tape had been developed, it was removed from the glass. To accomplish this, the glass is first submerged in DI water at room temperature for 20 minutes. Next, the tape was slowly peeled off of the glass using a piece of Mylar^{TM} as a wedge. This painstaking process can take 30 minutes per sample in the best of circumstances. More investigation is needed into better ways to achieve a flat base without peeling the tape off the glass.

Once the tape was fully removed from the glass, it was laminated in a hydraulic press. Recall that up to this point the two layers of tape have been laminated together only by hand rolling, which is highly irregular in terms of pressure and sometimes temperature. The two-layer structure was placed in the press and subjected to 4000 psi at 85°C for 15 minutes, with a 180° rotation of the piece halfway through the lamination to insure that all areas receive the same amount of pressure.

The tape was then ready to be fully fired. The current method for filling the cavities in the tape with the Ag-Pd paste is to use a spatula to spread the paste over the entire area by hand, and then to remove the excess using an acetone-soaked paper towel. Because the tape was still in the green state, however, the acetone would have etched it, so the tape needed to be fired before the paste could be applied.

Multiple layers were processed by this method, and then “glued” together using a low-temperature glaze, DuPont QQ550®. The QQ550® was placed between the layers, and then the sample was placed in the furnace again. This time the sample was brought to 550°C on a 10°C/minute ramp and held there for 30 minutes.

2.1.2 Results

The process described above was followed on multiple pieces of tape. Combining two layers of the photoformable into a single unit proved to be the most useful and reliable method for fabricating the spiral and preventing it from breaking. At first, a single spiral was fabricated and compared to past sensors. It was expected that the side walls of the spiral would not be very well defined, but the technique described above provided some surprisingly straight side-walls and definition, as can be seen in Figure 9. The photoformable tape has a tendency to curl up when in the furnace. To prevent this, the tape was sandwiched between two pieces of polished silicon wafers. The use of these wafers coupled with the use of a base for the spiral led to the creation of some flat and well-defined spirals, as evidenced by Figure 10.

Figure 9: Straight Side Walls with High Definition

Figure 10: A Fully Fired Spiral Made from Photoformable Tape

After the tape had been fully fired, it was very rigid needed less delicate treatment because the two-layer unit was comparatively strong. Once it had been fired, the spiral needed to be filled in with the Ag-Pd paste. The method employed, spreading paste over the entire area and then cleaning up whatever was possible, left much to be desired. Firstly, this process is difficult to automate, and automation of the entire procedure is the ultimate goal. Secondly, lots of paste was left spread over a wide area, which contributed to more parasitic capacitance than if the paste had been confined to the cavities.

Figure 11 shows a spiral filled with paste after it has been fired. The dark and uneven coloring on the ceramic is due to the fact that the primitive cleaning method left more paste on certain areas had more paste left on them than others. Another disadvantage of this method is its tendency to cause cracks in the paste. Although this does not break electrical continuity, it does change the local thickness of the paste, and can cause “hot spots,” areas that heat faster than their surroundings. Although the picture is blurry, this cracking in the paste can be seen in the upper left corner of Figure 12.

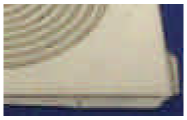


Figure 11: Uneven Coloration Due to Excess Paste That Could Not be Wiped Off.

Figure 12: Cracking of the Paste Due to the Method Employed.

Attempts to find a better method of filling the cavities in the tape were made. One such method tried was screen-printing the paste into the cavities while the tape was in the green. Unfortunately, the available screen-printer had no alignment system, and the screen was very difficult to see through. This method was no better than the spatula method, although automated and done while the tape was in the green. Because it was difficult to see the tape, a permanent marker was used to color the tape. After firing, this coloring made the piece look as if it had been burned, which is aesthetically unpleasing. The importance of sandwiching the tape between two layers of silicon wafers was shown with this particular sample as well, as can be seen in Figure 13. Notice the waviness of the tape due to certain areas curling up. Also notice a rather large fracture in the tape due to the stress introduced when one area curled and the neighboring area did not.

Figure 13: Illustrates the Need for Sandwiching the tape Between Two Silicon Wafers During Firing. Also Shows Burnt Coloration Due to Permanent Marker.

2.1.3 The Sensor

Once some spirals had been completed, line width, ceramic width, and pitch were measured. The resolution of the center square and the square at the top of the spiral was also made. Several measurements were made by two people averaged together to determine means and standard deviations. The table in Figure 14 shows these measurements and the drawing shows what these measurements refer to.

	Mean (um)	Std. Deviation (um)
Ceramic Width	537.5	5.01
Line Width	495	12.91
Pitch	1032.5	12.58
a	732.5	12.58
b	602.5	5.01
c	732.5	5.01
d	667.5	15.01

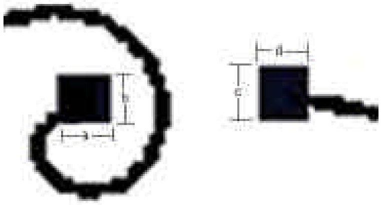


Figure 14: Achieved Resolution Measurements of Various Parts of the Spiral

Recall that one reason that photolithograpic processes were sought to create this sensor was to reduce the resistance. Measurements were taken on a single spiral layer and compared with previous results [5]. Measurements of capacitance and inductance were also included, but it is difficult to compare these to the previous results because they cannot be extrapolated by simply multiplying the value for one layer by the total number of layers. This comparison is shown in Figure 15.

	Previous Results	Previous Results Per Layer	Single Layer Results
Inductance	50 uH	N/A	2.72 uH
Capacitance	10 pF	N/A	57.37 nF
Resistance	120 Ohm	24 Ohm	4.885 Ohm

Figure 15: Comparison of Previous Results[5] with Current Results.

The current method has cut the resistance value by a factor of 5. This reduction in resistance reduces the damping effect, and allows for a higher value of the maximum current that can be passed across the sensor.

The most recent result in photoformable tape is shown in Figure 16.

Figure 16: A 2-layer Sensor. Unfortunately, Both Layers Are Oriented in the Same Direction, so No Resonance was Observed, as There Was No Inductance.

A two-layer coil was created in the photoformable tape. Unfortunately, both layers of spiral were oriented in the same way. The current passed counterclockwise on the top layer, and clockwise on the bottom layer, which cancelled out all magnetic flux, negating all inductance. Once it was determined that this was the cause, an attempt to create a full eight-layer sensor was made. Many layers broke in the attempt to remove them from the glass. At this point, all usable tape was exhausted. All remaining tape had either been exposed, stored improperly, or was just tiny scraps. Since photoformable tape is a research material and thus cannot be bought commercially, and since DuPont sometimes takes months to send new tape, the only option left was to switch materials.

2.2 Riston

Research on creating a proximity sensor using Dupont's Riston® 9015 was the logical next step. Work on proving the viability of using this photoresist with LTCC tape and improving the process was done this summer and will be reported in the coming IMAPS conference proceedings [8].

2.2.1 Process

The process involved in patterning LTCC tape using Riston® as a photoresist is similar to that used for patterning the photoformable tape. The process is summarized in Figure 17 below, followed by a discussion of the differences between the two processes.

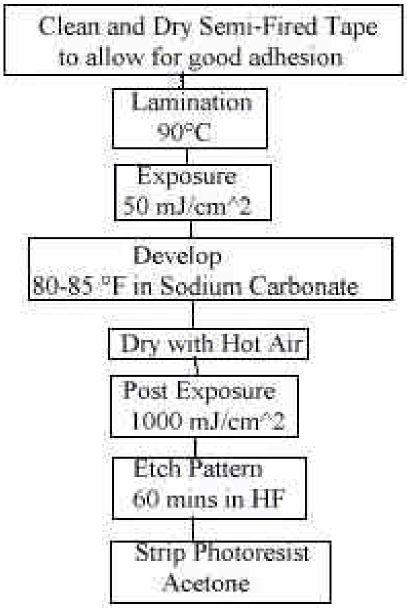


Figure 17: Process Summary for Use of Riston® as a Photoresist

The first difference between this process and the previous one is that the substrate is now DuPont's 951® LTCC tape. This process utilizes semi-fired tape, because this tape was more easily etched in the HF solution and allowed for a faster etching time than would be capable if a fully fired tape was used. This process did not require lamination onto a piece of glass because the semi-fired tape had already established its shape and would not warp. Thus, the corners of the tape could simply be taped to the glass during development.

The first step in this process was to clean and dry the semi-fired tape. Acetone was used to clean the tape, and was then rinsed off under a stream of DI water. It was suggested that the tape be dried using pressurized nitrogen [8]. However, the tape is fragile and this stream of pressurized air usually fractured it. Thus, five minutes on a hot plate at 90°C was substituted for the use of pressurized air in drying the tape. After the tape was clean, the Riston® was prepared. The layer of polyolefin protecting the glue was peeled back and the Riston® was laminated onto the tape at 90°C using a cotton swab to make sure no air bubbles formed between the LTCC and the Riston®. Bubbles can lead to unwanted etching or de-lamination of the tape from the Riston®. The photoresist was laminated onto both the front and back of the tape because the etchant surrounded the tape, and all sides needed to be protected.

Once all samples had been laminated on both sides with Riston®, they were ready to be exposed. The samples were exposed under a mercury arc lamp to an energy of 50 mJ/cm^2 measured at a wavelength of 365 nm. The mask was then removed and the back of the sample was exposed to the same energy, to protect it from the developer. The Riston® processing guide states that the photoresist can withstand a hold time of up to several days without any deterioration of development definition [9]. However, a delay of even 1 hour caused the Riston® to develop incorrectly, and in some cases not at all. Thus the samples were taken directly from the mask aligner to the developing machine. The samples were developed in sodium carbonate, Na_2CO_3, at 80-85°F. This photoresist seems to be much less dependent on the temperature of the developer, and the sample was usually fully developed after 15 seconds. After drying in hot air, both the front and the back of the samples were then exposed to an energy of 1000 mJ/cm^2 measured at 365 nm to strengthen the resist.

The etchant used in this process is HF:H_2O 1:4 at room temperature. This is a strong acid, so the samples were re-exposed to the UV light after development. The samples were suspended in the HF solution for 60 minutes, while a magnetic stirrer pushed the liquid around the samples. After that, the samples were submerged in running tap water to wash off all HF and then placed in acetone to strip off the Riston®. The samples were then either air dried or placed on a hot plate to dry.

2.2.2 Results

Two spirals and one set of vias were created using this process. Figures 18 and 19 show one of the spirals and the one set of vias that were realized, respectively.

Figure 18: A Spiral Realized Using Riston®   Figure 19: A Set of Vias Realized Using Riston®

Problems were encountered when creating a base layer for these samples. Because the 951® tape shrinks when fired, it is necessary to put two semi-fired pieces of tape together. However, holes must be punched in the base layer to allow for electrical continuity between layers. These holes are punched when the tape is green, and move when the tape shrinks in the furnace. How these holes move must be accurately described before alignment between the base and patterned layers can be realized.

The spiral layers created by this method are extremely flexible, as can be seen from Figure 20, in which the spiral is loaded by its own weight. Applications for this flexibility have not yet been explored.

Figure 20: A Spiral Realized From Riston® Process, Loaded by its Own Weight. Note the Flexibility of the Sample.

The most recent samples fabricated using the Riston® process are shown in Figures 21 and 22. These are the same samples shown in Figures 18 and 19, after having been laminated onto another piece of semi-fired LTCC with QQ550® and fully fired. Note the relatively large amount of bubbling and tearing of the substrate. The firing ramp, 10°C/minute, may have been too fast for the materials to handle. Although the QQ550® should be able to handle a full firing cycle, this bubbling of the substrate may prove that the glaze in fact cannot handle this temperature range.

Figure 21: Spiral From Figure 18
After Lamination and Full Firing

Figure 22: Vias From Figure 18
After Lamination and Full Firing

3. Conclusions

The original goal of this project was to create and then characterize a proximity sensor in photoformable LTCC tape. Although this goal was never realized, the process used to expose and develop these tapes was improved to the point that the sensor should be easily fabricated once more tape can be acquired. Further improvements in the procedure to achieve good alignment can lead to the process being fully automated and the ability to work with the tape in the green. This will significantly cut down on the time needed to produce a sensor, as all but one of the firing steps can be eliminated.

Once the photoformable tape was exhausted, the focus of this research shifted to work with Riston® as a photoresist. Work with this material was limited to adjusting the process parameters that were previously reported [8]. This procedure still needs to be researched to perfect the reliability of the process and to cut down on the amount of work done by hand in a serial manner. Explorations into batch processing with this material will prove rewarding. More work needs to be done in understanding the interaction between the semi-fired pieces of LTCC tape and the QQ550® so that results such as the ones shown above can be avoided.

Ultimately, this research will lead to the creation of proximity sensors using both methods, and these results will be compared with each other and the traditional silicon sensors now on the market. Because these materials are much cheaper than silicon and more thermally stable, sensors made in this fashion should take over markets where meso-scale parts are acceptable.

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