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A Review on LTCC based technology

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ABSTRACT

Low temperature Co-Fired ceramic(LTCC) is a technology used to fabricate devices in multilayer. It is a desirable technology due to its robust nature and low-cost multilayer device fabrication process. Now it is used in so many applications such as RF equipment, sensors, embedded passive component devices, rugged packaging, actuators, etc. In this paper, various uses and advantages are discussed of LTCC technology. It has opened a new dimension to device fabrication.

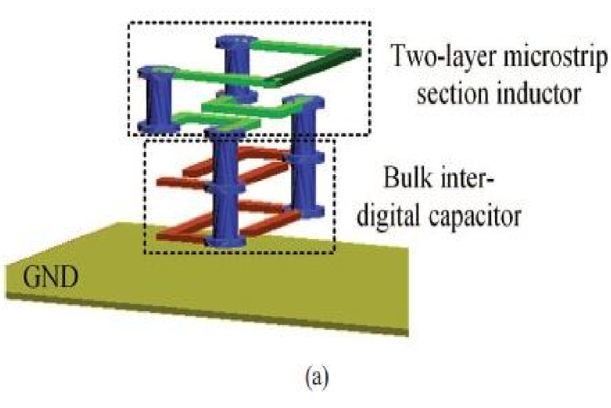
Key words: LTCC, packaging, sensors, microsystem, microchannel, micromachining.

1. INTRODUCTION

Ceramics are chemical resistant, heat resistance, and have high mechanical strength[1]. There are different types of ceramic glass composition used for its rigid bonding[2]. Low temperature Co-Fired ceramic is also a mixture of ceramics and glass, becoming an exciting topic due to its thermal, electrical, and mechanical properties. Due to its characteristics, it is used in a wide variety of applications like communication equipment, consumer product, biomedical equipment, etc. LTCC can fabricate different components like active, passive, and microstructure in a single compact package. It has a significant advantage of error correction during the fabrication of components by removing the faulty layer [3]. Generally, it looks like a green tape. It is a form of material composed of glass and ceramics which alter the properties and make it more useful for fabricating components. Ceramics are used for the very high-quality component, which can withstand the very harsh environment but to fabricate components with ceramics its needs very high temperatures. A component is composed of different types of material, and those materials also have to sustain those high temperatures to fabricate components on pure ceramics. To make a component with ceramics almost or higher then 1600 degrees Celcius is needed, and it is a costly process to maintain the temperature. Other materials used for this fabrication process also will be expensive. It is a disadvantage as it increases the cost of fabrication. But when the glass is mixed with ceramics, the fabrication temperature reduces, which is a comparatively less valuable material that can be used. Thus device fabrication costs reduce [4].

LTCC is widely used because of its multilayer structure, low manufacturing cost, good quality passive device fabrication and integration, packaging, miniaturization, etc. Microstructures fabricated uniformly [5]. It can be fabricated using of the thick-film process [6]. It has high reliability and stability. There are a few steps to fabricate an LTCC device. At first, the green tape is manufactured with the ceramics and glass. Both materials contributed to the characteristics of a manufactured device. This green tape is placed layer after layer to fabricate multiple components and devices. In the green tape, vias or holes are made, filled by conductive material paste to make the interconnections of a different component. These vias or holes can be made by punching or laser cutting. During the laser cutting, shrinkage is a common phenomenon of green tapes; that's why it makes a little bigger than the required one. These vias are used for the interconnection of components and layers. Then another material is deposited on the green tape to make the component. There are few methods to deposit component material on green tape like screen printing, inkjet, etc. Among this, screen printing is the most widely used method. After the deposition of component material and interconnections are made, the tape is laminated together using temperature and pressure. These laminated layers of green tape together and then heated at 900 degrees Celsius. Hence an LTCC device manufactured at low temperature. In this method, both embedded and bare components are manufactured. The three-dimensional microstructure can be made a straight forward process, which increases the capability of new devices [7]. Multiple sensors and circuits with energy driving parts can be fabricated [8]. Now, this technology is used in communication devices, micromachining techniques, passive component fabrication, sensor fabrication, hybrid circuits, Microsystems, etc. Here, LTCC is discussed to find out the reason for the popularity of using LTCC substrate, and it seems that LTCC is a significant breakthrough in device fabrication considering cost and performance due to its rugged packaging, high thermal stability, and good electrical and magnetic properties which is shown here.

1.1 Communication Equipment: Very few dielectric materials can work well with >100GHz frequency with fewer losses. For communication equipment, low dielectric losses, low-temperature dependence, and constant dielectric stability over a wide frequency range is an essential factor [9]. LTCC is becoming crucial for high-frequency microwave communication because of its excellent dielectric properties. It can show very stable dielectric properties over a wide range of frequencies [10]. It has a lower dielectric constant and dielectric losses at very high frequencies [11]. A lower dielectric constant is mandatory for a high data transmission line as the lower the dielectric constant higher the signal propagation rate. It has excellent flexibility and lower manufacturing cost for mm or sub-mm wave devices. Sub-mm devices are tiny in the range of a few square millimeters, making it difficult to fabricate a better quality component. LTCC is an excellent solution for this as it has high flexibility and low manufacturing cost. In this technology, small size high-quality components can be reproduced with significantly lower tolerance. It is seen that when a chip is integrated with a passive component in the millimeter-wave range, then the performance of that integrated circuit is considerably degraded, and this performance can be increased by using LTCC technology. Filters, transmitters, receiver, antennas are made in a single small package. High-frequency high bandwidth antenna can be designed using LTCC in a single module. In this antenna, multiple resonators can be used where each resonator can resonate in a different frequency. Electric coupling of multiple feeding lines of an antenna in multiple layers of the resonator with increased performance can also be done comfortably, as shown in Fig-1 [12]. Thus a multi-band high bandwidth small size antenna can be manufactured. Microwave filters can be designed by fabricating lump elements such as inductors and capacitors using LTCC, which has reduced size. The compact Radar sensor can be designed by integrating a monolithic microwave integrated circuit (MMIC) with electromagnetic bandgap transmitting and receiving antennas. It is also possible to fabricate a transmitter, receiver, antenna in the same package without doing any solder, which helps to miniaturization. Different types of waveguides, like Coplanar Waveguide(CPW), Grounded Coplanar Waveguide(GCPW), also can be fabricated, which has low insertion loss using LTCC technology [13].



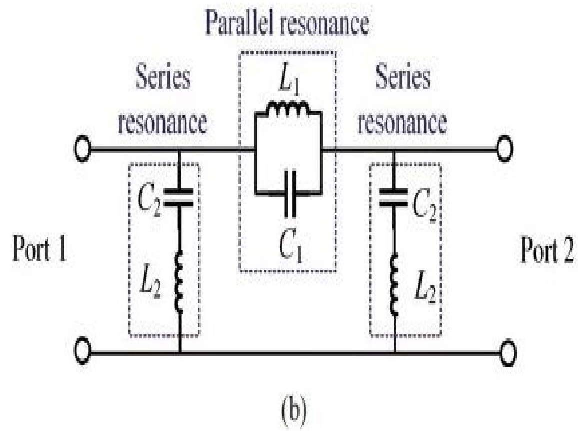


Fig-1: a) LTCC based multiple resonator 3D diagram b) Equivalent circuit of (a) [12]

1.2 Packaging: Proper packaging of high-density components increased the lifetime, robustness, and performance of the microelectronic circuit and LTCC packaging is the best considering all those factors. System miniaturization is a challenge for technology and system in a package(SiP) or system on package(SOP) by LTCC, meeting the demand with very high portability, reliability, and stability. In a single package channel, microcantilever, optical, electrical, mechanical components can be fabricated. For communication equipment, the antenna-in package(AiP) makes the antenna within a single module, reducing the size of equipment. It is also very cost-efficient packaging because of its excellent thermal properties [14]. The multifunctional device can be made as a single module using LTCC. That is why it's using for military equipment, biomedical equipment, aerospace, communication equipment, etc. In these packages, not only high-density passive equipment can be fabricated; it can also be used to integrate multiple chips on a single package using flip-chip technology with a smaller form factor [15]. It is also possible to fabricate complex compact modules that do not need any external devices. On the LTCC substrate, a high density of a thin-film layer can be formed as its surface is very flat, and more packages can be produced then the circular wafer, which can reduce time and cost [16]. Fig-2 shows the packaging of the LTCC device. During the fabrication of the microsystem, as the density of components increases, heat generation also increases, and LTCC has a proper thermal coefficient and good heat resistance. When a high power device is fabricated in a module, it will also produce high thermal energy. It is difficult to place those components in a small place that can handle high power, which needs good thermal stability and low deformation of the substrate where the component is placed. LTCC can handle it well by fabricated those high powered components in a different layer. Due to its good heat resistance and to minimize the heat dissipation of components, a right heat sink can be fabricated within LTCC. Different categories of channels can be fabricated to reduce the heat in its package, and fluid or air is flown in those channels. Due to its heat sink fabrication ability, high heat produced components is fabricated on LTCC. In other fabrication processes, the device is fabricated mostly in a two-dimensional process. In LTCC, the component is fabricated in three dimensional, which makes the packages more compact.

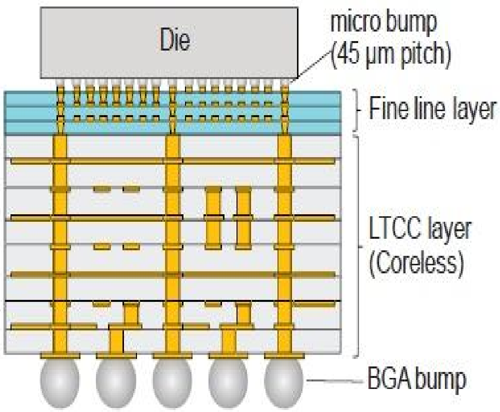
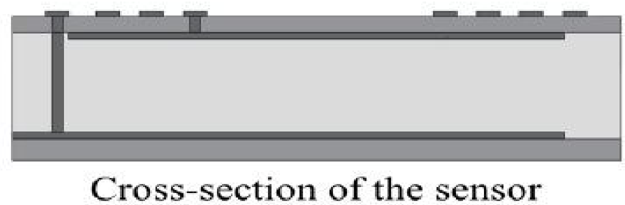
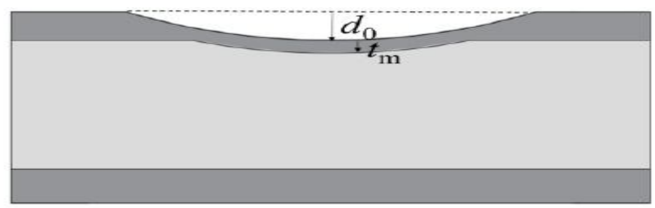


Fig-2: LTCC packaging[16]

1.3 Sensor: A sensor is a device that can convert a physical, chemical, or mechanical changes of material to an electrical signal. Its generally used to collect the information of surrounding and interpret to appropriate format. This sensor can be placed in a controlled environment or unstable environment to know the different statuses of the surroundings like temperature, pressure, humidity, bio substances, chemical properties, etc. To manipulate an environment properly, it has to be very stable and also very rigid so that it can sustain an environment like heavy humidity, high temperature, etc. Silicon-based sensors are not very good heat or humidity resistance. On the other hand, LTCC based sensors can withstand very severe conditions. It has better chemical, thermal resistance than silicon. Using LTCC, a large number of different type of sensor are fabricated in an array then interconnected, which produce better output result. Sensors have a sensing layer, which is the most crucial part. The performance of the sensors sometimes depends on the thickness of the sensing layer, which can be significantly controlled in LTCC. A pressure sensor is built by fabricating a parallel plate capacitor inside the LTCC package. One of the parallel plates is fixed, and another plate with the LTCC surface is used to take the load. The good elastic material is used as a capacitor dielectric material. This capacitor is built within the ceramic tapes. When the pressure exerted, there is a deformation of the parallel plate and dielectric material, which changes the capacitance. Thus pressure is measured by detecting capacitor changes, as shown in Fig-3 [17]. For biosensor, the microheater is an essential part which can be fabricated with LTCC or silicon. Silicon-based microheaters have low power consumption but high manufacturing costs; on the other hand, LTCC based micro heaters are cheap. These heaters can be buried or on the surface in LTCC and just placed underneath the sensor. Due to the low thermal coefficient and good heat stability, all heats produced by the heater are used more efficiently for the sensor. A passive wireless gas sensor also can be fabricated on LTCC. The capacitor and inductor fabricated in LTCC and microheater placed under the capacitor than a sensing layer deposited over the two plates of the capacitor. When the sensing layer came into contact with the gaseous molecule, then the parallel resistance of the capacitor changes, which is used to detect the type of gaseous molecule [18]. Microcavities and micro preconcentrator can be fabricated, and the sensing layer can be placed in there to detect biomolecule [19].



(a)



(b)

Fig-3: LTCC/PDMS pressure sensor (a) structural design (b) Mechanical design[17]

1.4 Microsystem: Microsystem has a growing demand for all kinds of electronic equipment. It has to be compact, long-lasting, movable, and easily integrable. LTCC based Microsystems demonstrated more flexibility and more reliability with an easy fabrication method. It's beneficial for the microsystem because of chemical resistance, mechanical stability, and temperature resistance. In this system, a lot of different types of mechanical, electrical, and electronic components in a single module can be fabricated, and the interconnection of those components done comfortably. Multiple sensors, channels, cavities, actuators, and different types of signal transducer units with different active and passive devices can be integrated within a small LTCC platform to act as a microsystem with multifunction. LTCC can integrate the active and passive component in multilayer. In each layer, components can be made, and then every layer can be stacked one by one, which reduces the size of the equipment. A component can be manufactured horizontally as well as vertically. It has an excellent thermal coefficient, a key parameter to manufacture a high density of mounting chip. It can use the flip-chip technique to mount a chip, and multiple chips also can be mounted in a single module. Thus hybrid circuit can be manufactured. High-density semiconductors can be fabricated in LTCC.

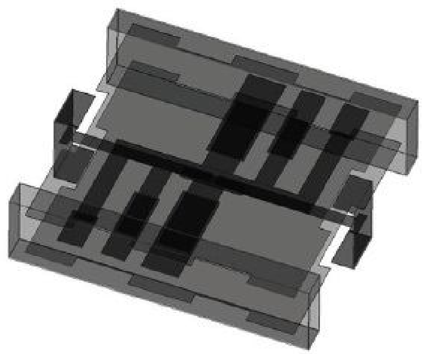
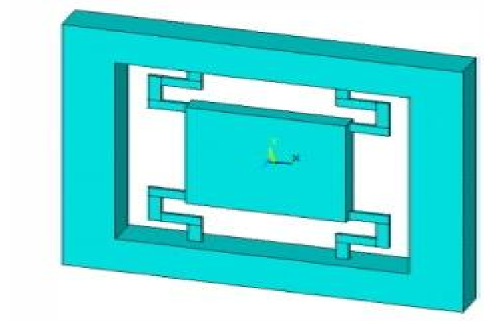


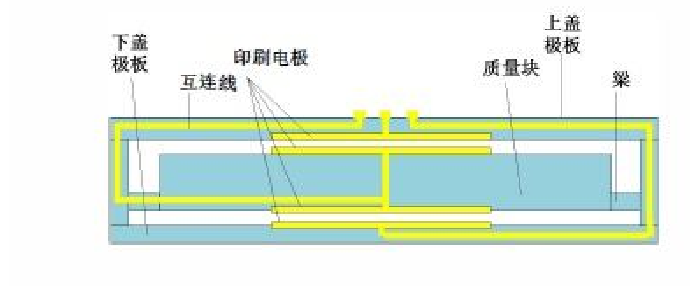
Fig-4: 3D structure of a microsystem of dual passband filter[22]

It is challenging to fabricate lines and via diameter in the micrometer range, and LTCC eases the complexity by fabricating those in tens of micrometer range. It can be used to design a thermocouple based power source, and the advantage of assembling thermocouple in LTCC is its very low thermal conductivity. Series of thermocouple can be fabricated in a layer, and then it can be stacked with another layer; thus, many layers of the thermocouple is produce as a single compact module and work as a microsystem of the thermoelectric generator [20]. A thin diaphragm (100um) and a thin cavity(height 50um) can be fabricated in LTCC [21]. RF circuit passive component and integrated circuit always need a higher amount of space, and very difficult to minimize this without degrading the component performance. A microsystem of the passband filter is shown in Fig-4. LTCC multilayer fabrication makes it possible to reduce the size of the microwave circuit. Dual-band filter, balun, antenna all can be placed in a small package. It can be seen dimensions of X-band Ultra wideband balun, highly steep bandpass filter, Ultra-wideband planar magic T, ultra-wideband Vivaldi antennas on LTCC is only about a few millimeters [22].

1.5 Micromachining: Micromachining is a technology that is used to make a shape geometrically in the range of micrometers. This geometrical shape can be fixed or movable. Micromachining is done in a microelectromechanical system (MEMS). Those systems are generally based on silicon, and silicon is not that hardy. To protect those micromachines from an extreme environment, LTCC is used as it is more mechanically stable. It is also can be used as a sensing element to detect mechanical displacement. Sometimes LTCC is also used as a machined element instead of a silicon compound to fabricate actuator. Micromachining in LTCC can be used to fabricate pressure sensors, accelerometer, temperature sensor, etc. Using silicon in MEMS technology is expensive and sophisticated, whereas LTCC is a cheap and easy process though complete LTCC based MEMS is taken larger space than silicon-based MEMS. An accelerometer is built by LTCC, where two capacitors are fabricated. This accelerometer has several layers of green tape, and inside the top layer and bottom layer, a mass block is suspended. That mass block is suspended by elastic material and the elastic material joined with the other LTCC layer between the top and bottom layer.



(a)



(b)

Fig-5: Acceleration sensor using micromachining of LTCC (a) Suspended mass block (b) Cross-sectional view[23]

Each capacitor, one of the plates is fabricated inside the top and bottom layer, and the plate of the two capacitors is fabricated outside of the suspended block. Thus two capacitors formed, and when there is acceleration, the suspended block moves, and there is a change in capacitance of those two capacitors. By measuring the differential capacitance, acceleration can be calculated, shown in Fig-5 [23]. Micromachined cavities are fabricated in LTCC, which can be worked as a surface integrated waveguide. This waveguide is used for microwave and mm-wave filter, resonator, oscillator, etc. [24]. Heat generation in the semiconductor device is another critical issue, and this heat can be transferred by thermal via or channel. This channel has to be made in the micro or nanometer range, and fluid can flow through that channel, challenging to achieve; this can be done by LTCC based module and using the micromachined technique, a microfluidic channel can be fabricated [25]. It is also possible to create a valve to control the flow of fluid in LTCC [26].

2. CONCLUSION

For miniaturization, robustness and high performance of a device, always high prices, and more sophisticated equipment with advanced knowledge required. But LTCC has the characteristics which can meet all the requirement for packaging to downsize equipment without degrading the performance. It also has good compatibility with the thick film paste technology, so there is no extra equipment or cost. It can convert a bigger machine into a small one. It is evident that we have a significant benefit using this technology.

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