UNIWERSYTET TECHNOLOGICZNO-PRZYRODNICZY
IM. JANA I JĘDRZEJA ŚNIADECKICH W BYDGOSZCZY
ZESZYTY NAUKOWE NR 258
TELEKOMUNKACJA I ELEKTRONIKA 14 (2011), 5-12

DESIGN AND TECHNOLOGY OF HYBRID MULTILAYER ELECTRONIC CIRCUITS

Dominik Jurków, Karol Malecha, Mateusz Czok,
Henryk Roguszczak, Michał Babiarz, Leszek Golonka

Faculty of Microsystem Electronics and Photonics
Wrocław University of Technology
50-372 Wrocław, Janiszewskiego 11/17, building C-2, Poland
dominik.jurkow@pwr.wroc.pl

Summary: The design and technology of hybrid electronic ceramic circuits with flip-chip and SMD (Surface Mounting Device) components are presented in the paper. The flip-chip audio amplifier and RF (Radio Frequency) transmitting and receiving modules are fabricated using LTCC (Low Temperature Co-fired Ceramics). X-Ray inspection is performed to analyze the solder bonding quality. The application of special underfill has increased the reliability of interconnections between flip-chip, SMD components and the ceramic multilayer substrate. The final structure of the audio amplifier module is encapsulated with ceramic housing.

Keywords: flip-chip, LTCC, X-Ray, thick-film, SIP

1. INTRODUCTION

The size of an electronic package is one of the most significant miniaturization factors. The size of a package is limited by the interconnection pitch. The flip-chip technology [1, 2], which is an advanced form of SMT (Surface Mounting Technology), is one of the most significant assembly developments. The method increases device reliability and productivity and simultaneously reduces costs. The flip-chip is a bare silicon chip which consists of solder pads placed on the whole bottom surface. In contrast to the common use of the wire-bonding technique, the flip-chip assembly method enables the bonding of all interconnections in one step and bonds devices with I/O placed on all bottom chip areas. Moreover, flip-chip technology allows the attainment of very high interconnections reliability and electric performance (low serial resistance, capacitance and inductance). However, the wire bonding method is still most often used in low density interconnection bonding <700 I/O on a single chip. The flip-chip technique is the main technique of higher interconnection density assembly. One of the main problems in assembly technique is mismatch between thermal expansion coefficients of chip and substrate. Epoxy laminates are the most common substrates in electronic industry. However, thermal expansion coefficient mismatch between epoxy and silicon is quite high. Therefore, interconnection reliability is decreased. The problem can be reduced by using organic underfill which decreases thermal expansion coefficients mismatch between both materials. Moreover, the thermal expansion coefficient of new glass ceramics (Low Temperature Cofired Ceramics - LTCC) substrates is fitted to silicon. Therefore, the LTCC technology is compatible with the flip-chip technique.

The low Temperature Cofired Ceramic technique was developed around 30 years ago. The method was applied in the fabrication of hybrid multilayer electronic circuits [3-5]. The main advantages of LTCC are good long term stability and mechanical properties, compatibility with standard thick film technology and low cost. The interconnection density can be increased by using buried screen printed passive components. The standard LTCC process [6-7] consists of the following steps: design, via and shape cutting [8,9], thick film deposition and lamination [10,11] and cofiring. The ability to form 3D shapes and compatibility with the thick film technique enables us to fabricate various sensors [12-16], actuators [17, 18], microsystems [19,20] and wireless transmission devices [21,22] using LTCC technology.

The design and technology and inspection of hybrid electronic ceramic circuits with flip-chip and SMD components is presented in this paper.

2. RF MODULES ELECTICTRICAL CIRCUIT DESIGN

The electrical circuit of RF transmitter integrated with the LTCC module is presented in Figure 1. The electronic circuit consists of ATmega88 microcontroller, monolithic temperature and humidity sensor SHT11, radio frequency transmitter (RFM02), fixed-output voltage regulator (LM2980IM5-5.0) and additional passive components.

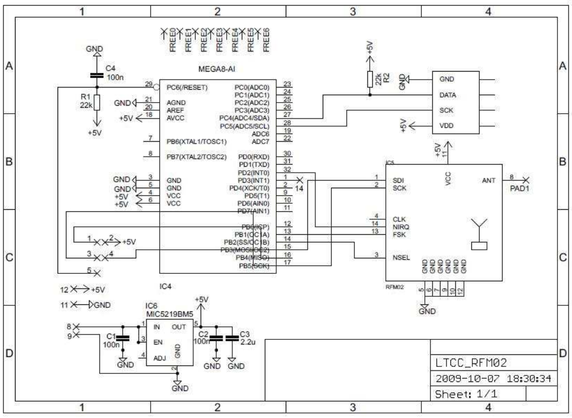

Fig. 1. Electrical circuit of RF transmitter module.

The electrical circuit of RF receiver integrated with LTCC module is presented in Figure 2. The electronic circuit consists of ATmega88 microcontroller, radio frequency receiver (RFM01), fixed-output voltage regulator (LM2980IM5-5.0) and additional passive components. Both modules were assembled to additional electronic circuits. The additional circuits consist of power supplies, LCD displays and RF antennas.

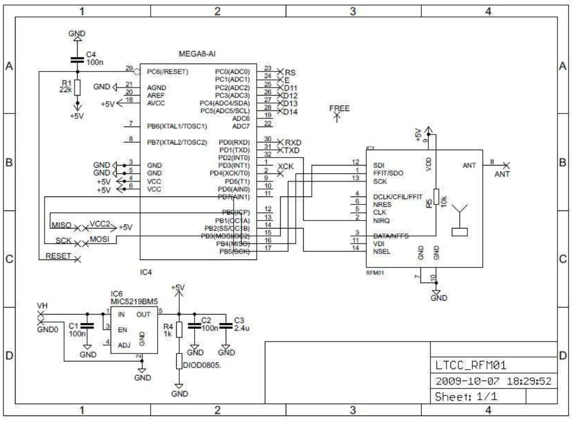

Fig. 2. Electrical circuit of RF receiver module.

3. TECHNOLOGY OF RF MODULE

The LTCC multilayer module consisted of two DP951 P2 green tapes: TOP, BOT, and two DP951 C2 tapes M1 and M2. The thickness of DP951 P2 and DP951 C2 tapes after firing was approximately 165 µm and 50 µm, respectively. The TOP and BOT layers consisted of surface conductive lines and solder pads, the M1 and M2 provided better mechanical properties of the ceramic module and masked the electric trucks. Therefore M1 and M2 layers were used as solder masks. The LTCC tapes were laser cut to proper dimensions and via holes were drilled. The silver paste DP 6141 was used to fill the vias. The silver paste DP 6145 was used to deposit electrical trucks. The silver palladium paste was used to deposit solder pads. The screen printing method was used for via filling and deposition of electric trucks and solder pads. After screen printing all ceramic tapes were stacked together in the proper order and laminated using an isostatic press with a pressure of 20 MPa at 70°C for 10 minutes. Finally, the LTCC multilayer module was co-fired in air in a two-step firing profile recommended by DuPont (Tmax = 850°C). The final fired structure with solder mask is presented in Figure 3. Substrates were assembled with SMD components. The final receiving and transmitting modules are shown in Figure 2a and 2b, respectively. The additional electronic circuits which consist of power supplies, LCD displays and RF antennas were fabricated with standard PCB (Printed Circuit Board) and SMT techniques. Power consumption of the devices was significantly decreased with the use of ATMEGA sleep modes and turning down unused microcontroller peripherals. The average current consumptions of transmitting and receiving modules were approximately 440 µA and 14 mA, respectively. The transmitting range was equal to 60 m in the open area.

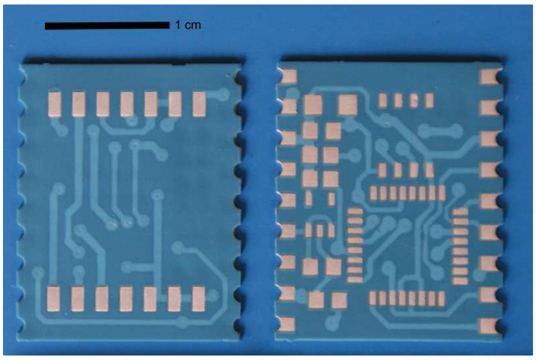

Fig. 3. Final fired multilayer substrate.

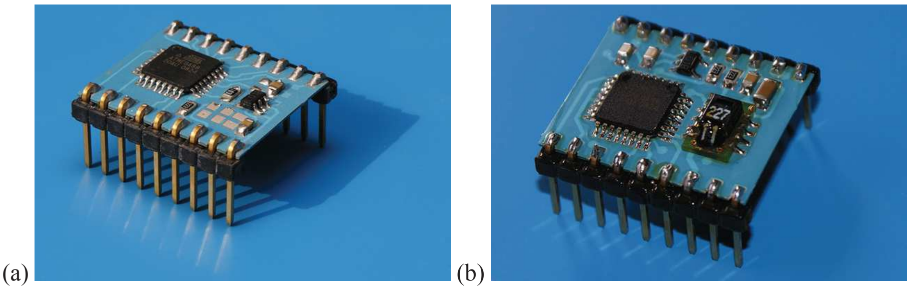

Fig. 4. Final device, (a) receiver, (c) transmitter.

4. FLIP-CHIP MODULE ELECTICTRICAL CIRCUIT DESIGN

The electronic circuit of the flip-chip stereo audio power amplifier integrated with the LTCC substrate is shown in Figure 5. The circuit consists of a flip-chip stereo audio power amplifier TS4984, four negative feedback resistors and four capacitors. Each channel of the TS4984 device can supply 1.2 W (8 Ω load at 5V) [23]. The amplifier is suited for mobile phones, LCD monitors, portable audio devices, and PDA computers, etc.

The gain (k) of each channel is given by equation 1. The gain is set by R_1-R_4 resistors. The gain of 4.5 times was designed.

$$k = \frac{R_1}{R_2} = \frac{R_3}{R_4} \tag{1}$$

Bypass capacitors C_1 and C_2 provide power supply filtering. Input capacitors C_3 and C_4 separate the DC voltage from the flip-chip input terminations. The low-pass filter is set by R_2, R_4 resistors and input capacitors C_3, C_4. The cut-off frequency is given by equation 2. The cut-off frequency was set to 72 Hz.

$$f = \frac{1}{2\pi R_2 C_3} = \frac{1}{2\pi R_4 C_4} \tag{2}$$

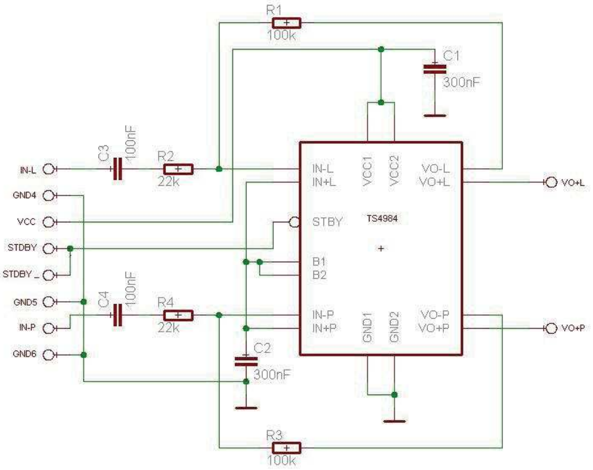

Fig. 5. Electrical circuit of stereo audio power amplifier based on flip-chip module TS4984

5. TECHNOLOGY AND POST INSPECTION OF THE FLIP-CHIP MODULE

The LTCC multilayer module consisted of four DP951 P2 green tapes: TOP, BOT, L1 and L2. The thickness after firing of each DP951 P2 tape was approximately 165 µm. The TOP layer consisted of surface conductive trucks and solder pads, the L1 and L2 layers consisted of inner conductive trucks and the BOT layer provided better mechanical properties of the ceramic module. The LTCC tapes were laser cut to proper dimensions. All conductive lines were made of silver palladium paste (DP 6146). Afterwards, vias were punched and filled with silver DP6161 paste with via filler. All ceramic tapes were stacked together in the proper order and laminated using an isostatic press with a pressure of 20 MPa at 70°C for 10 minutes. Finally, the LTCC multilayer module was co-fired in air in a two-step firing profile recommended by DuPont (T_{max} = 850°C). After firing the SMD and flip-chip, devices were assembled on top of the module and soldered with a precise flip-chip system (FC300 CAMMAX PRECIMA LTD.). The chip was encapsulated with underfill. The fired LTCC structure with assembled components is presented in Figure 6a. After the assembly of the SMD and the flip-chip components the ceramic module was housed. The package consisted of six DP 951 P2 LTCC tapes. The green ceramic tapes were laminated using the thermo-compression method (20 MPa at 70°C for 10 minutes). Next, the package geometry was formed with the CNC (Computer Numerical Control) microdrill and fired in a furnace in typical thermal profile. The top part of the package and final packaged LTCC module are shown in Figures 6b and 6c, respectively.

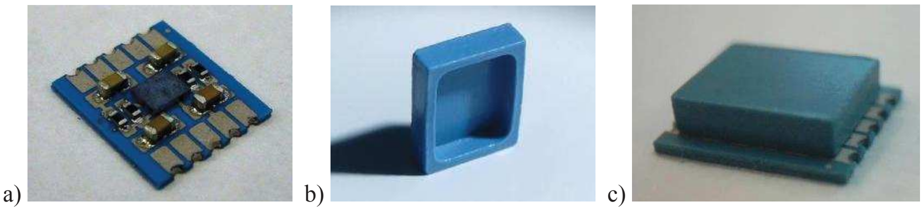

Fig. 6. Final device: a) assembled fired LTCC substrate, b) top housing part, c) housed structure

The alignment of the bare chip with solder pads after firing and the assembly processes was examined by a non-destructive X-ray tomography at ITR Warsaw. An X-ray image of the LTCC multilayer module with flip-chip is shown in Figure 7.

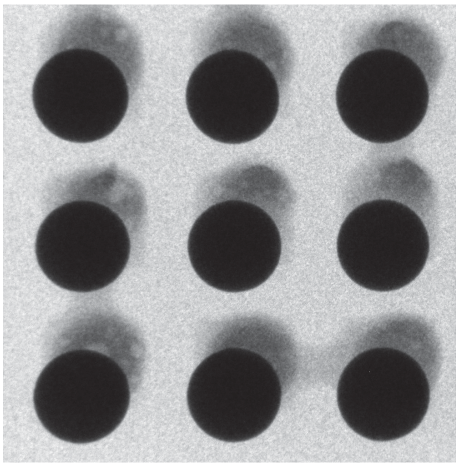

Fig. 7. X-ray image of the LTCC multilayer module

6. SUMMARY

The electrical circuit and layout of the RF transmitter/receiver and acoustic amplifier flip-chip modules integrated with LTCC substrates were developed.

Surface and buried electrical tracks were deposited using the screen printing method.

The multilayer LTCC RF modules were fabricated and tested positively . Their transmission range and power consumption were estimated to 60 m. and ca. 1.45 mW, respectively.

The semiconductor bare amplifier chip was encapsulated with underfill. Moreover, all electronic components were covered with ceramic housing.

The good alignment of the bare chip with solder pads after firing and the assembly processes was confirmed by X-Ray tomography.

The possibility of integration of surface electronic components (SMD, buried and surface screen printed passives and conductive tracks and flip chip devices) and package in one substrate enables us to fabricate sophisticated system-in-package (SIP) devices.

BIBLIOGRAPHY

[1] R. Tummala, 2001. Fundamentals of Microsystems Packaging, McGRAW-HILL, ISBN 0-07-137169-9.

[2] C. Harper, 2000. Electronic packaging and interconnection handbook, McGRAW-HILL, ISBN 0-07-134745-3.

[3] T. Gupta, 2003. Handbook of Thick- and Thin-Film Hybrid Microelectronics, Wiley-interscience, ISBN 0-471-27229-9.

[4] F. Barlow III, A. Elshabini, 2007. Ceramic Interconnect Technology Handbook, CRC Press/Taylor & Francis, ISBN 0-849-33557-4.

[5] L. Golonka, 2006. Technology and applications of Low Temperature Cofired Ceramic (LTCC) based sensors and Microsystems, Bulletin of the Polish Academy of Sciences, vol. 54, pp. 223-233.

[6] M.R. Gongora-Rubio, P. Espinoza-Vallejos, L. Sola-Laguna, J.J. Santiago-Aviles, 2001. Overview of low temperature co-fired ceramics tape technology for meso-system technology (MsST), Sensors and Actuators A, vol. 89, pp. 222-241.

[7] K. A. Peterson, K. D. Patel, C. K. Ho, S. B. Rohde, C. D. Nordquist, C. A. Walker, B. D. Wroblewski, M. Okandan, 2005. Novel microsystem applications with new techniques in Low-Temperature Co-Fired Ceramics, Int. J. Appl. Ceram. Technol., vol. 2, pp. 345-363.

[8] J. Kita, A. Dziedzic, L. Golonka, T. Zawada, 2002. Laser treatment of LTCC for 3D structures and elements fabrication, Microelectronics International, vol. 19, pp. 14-18.

[9] K. Nowak, H. Baker, D. Hall, 2006. Cold processing of green state LTCC with a CO_2 laser, Applied Physics A, Materials Science and Processing, vol. 84, pp. 267-270.

[10] M. A. Piwonski, A. Roosen, 1999. Low pressure lamination of ceramic green tapes by gluing at room temperature. Journal of the European Ceramic Society, vol. 19, pp. 263-270.

[11] H. Birol, T. Maeder, P. Ryser, 2006. Processing of Graphite-Based Sacrificial Layer for Microfabrication of Low Temperature Co-Fired Ceramics (LTCC), Sensors Actuators A, vol. 130-131, pp. 560–567.

[12] M.G.H. Meijerink , E. Nieuwkoop, E.P. Veninga, M.H.H. Meuwissen, M.W.W.J. Tijdink, 2005 . Capacitive pressure sensor in post-processing on LTCC substrates, Sensors and Actuators A, vol. 123-124, pp. 234-239.

[13] M. Gongora-Rubio, L.M. Sola-Laguna, P.J. Moffett, J.J. Santiago-Aviles, 1999. The utilization of low temperature co-fired ceramics_LTCC-ML technology for meso-scale EMS, a simple thermistor based flow sensor, Sensors and Actuators, vol. 73, pp. 215-221.

[14] M.H.H. Meuwissen, E.P. Veninga, M.W.W.J. Tijdink, M.G.H. Meijerink, 2006. Design study of a capacitive pressure sensor in non-silicon materials, Proceedings of the Institution of Mechanical Engineers, vol. 220.

[15] M.G.H. Meijerink , E. Nieuwkoop, E.P. Veninga, M.H.H. Meuwissen, M.W.W.J. Tijdink, 2005. Capacitive pressure sensor in post-processing on LTCC substrates, Sensors and Actuators A, vol. 123-124, pp. 234-239.

[16] W. Smetana, M. Unger, 2008. Design and characterization of a humidity sensor realized in LTCC-technology, Microsyst. Technol., DOI 10.1007/s00542-007-0465-3.

[17] H. Klumbies, U. Partsch, A. Goldberg, S. Gebhardt, U. Keitel, and H. Neubert, 2009. Actuators to be integrated in Low Temperature Cofired Ceramics (LTCC) microfluidic systems", Proc. 32nd IEEE International Spring Seminar on Electronics Technology, 13-17 May 2009, Brno (Czech Republic), pp. 1-4.
[18] E. Heinonen, J. Juuti, H. Jantunen, 2007. Characteristics of piezoelectric cantilevers embedded in LTCC", Journal of the European Ceramic Society, vol. 27, pp. 4135--4138.
[19] T. Thelemann, H. Thust, M. Hintz, 2002. Using LTCC for microsystems, Microelectronics International, vol. 19, pp. 19-23.
[20] L.J. Golonka, H. Roguszczak, T. Zawada, J. Radojewski, I. Grabowska, M. Chudy, A. Dybko, Z. Brzozka and D. Stadnik, 2005. LTCC based microfluidic system with optical detection, Sensors and Actuators B, vol. 111-112, pp. 396-402.
[21] A. Sutono, A. Pham, J. Laskar, W. R. Smith, "Development of three dimensional ceramic-based MCM inductors for hybrid RF/microwave applications", IEEE Radio Frequency Integrated Circuits Symposium, pp. 175-178, 1999
[22] A. Sutono, A. Pham, J. Laskar, W.R. Smith, 1999. RF/microwave characterization of multilayer ceramic-based MCM technology, IEEE Transactions on Advanced Packaging, vol. 22, pp. 326-331.
[23] Datasheet of TS4984 flip-chip Stereo Audio Power Amplifier.

The authors wish to thank the Polish Ministry of Science and Higher Education (grant no. R02 017 02) for financial support. Fellowship of Dominik Jurków co-financed by European Union within European Social Fund. The Foundation for Polish Science (FNP) is also acknowledged for financial support for Karol Malecha.

PROJEKTOWANIE I TECHNOLOGIA WIELOWARSTWOWYCH HYBRYDOWYCH UKŁADÓW ELEKTRONICZNYCH

Streszczenie

W pracy zaprezentowano projekt oraz realizację dwóch przykładowych hybrydowych układów elektronicznych: wzmacniacza audio opartego na elemencie typu flip-chip oraz nadajnika i odbiornika RF opartych na elementach do montażu powierzchniowego (SMD). Przedstawione układy zostały wykonane przy wykorzystaniu technologii bazującej na niskotemperaturowej ceramice współwypalanej (LTCC). Niezawodność połączeń lutowanych pomiędzy elementem typu flip-chip a polami kontaktowymi umieszczonymi na podłożu LTCC zbadano za pomocą metody rentgenowskiej. Poprawę niezawodności w przypadku układu z elementem typu flip-chip uzyskano stosując wypełnienie organiczne pomiędzy chipem a podłożem. Gotowy układ wzmacniacza audio zamknięto w specjalnie przygotowanej obudowie ceramicznej.

Słowa kluczowe: flip-chip, niskotemperaturowa ceramika współwypalana (LTCC), tomografia rentgenowska, warstwa gruba, SIP