Electrical properties of dielectric foil for embedded PCB capacitors

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One of the methods of achieving high packaging density of passive elements on the PCB is using the capacitors embedded in multilayer PCB. Test structures consisting of embedded capacitors were fabricated using the FaradFlex® capacitive internal layers. Impedance spectroscopy and equivalent circuit modelling was used to determine their electrical properties such as the capacitance, parasitic resistance and inductance. The use of several stages of accelerated ageing allowed us to test the durability of the structures. The results showed good quality stability of the embedded elements. The spatial distribution of the capacitance of the test structures on the surface of the PCB form was tested. The influence of the process parameters during lamination on the values of embedded capacitors was revealed.

Keywords: impedance spectroscopy, equivalent circuit, dielectric foil, embedded elements, PCB

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1. Introduction

One of the methods for increasing the density of elements on the printed circuit board (PCB) and reducing the number of soldered joints is the embedding of passive elements in the internal layers of the PCB [1–3]. It allows reducing the manufacturing costs and improving the electrical properties of passive elements.

The impedance spectroscopy is a useful method for determining the electric properties of materials and electronic devices [4, 5]. It is based on measurement and analysis of the electric response of an object excited with a small electromagnetic signal in a wide range of frequency – the impedance spectrum.

The impedance spectra are most often analysed using equivalent circuit modelling. This method makes possible to identify separately the phenomena which determine the electric properties of the object as well as its parasitic elements.

In this paper, authors present the results of investigation of dielectric foil properties and their changes during accelerated ageing identified using the impedance spectroscopy.

2. Samples and measurement system

The properties of commercial FaradFlex® copper coated dielectric foils were measured using planar capacitors embedded in the PCB. Two types of foils were used: BC24M polymer foil and BC12TM foil which additionally contained the high permittivity ceramic powder. These foils had thicknesses of 24 and 12 µm, respectively and the characteristic capacitance of 180 pF/cm² and 650 pF/cm², respectively [6, 7].

Each foil was used to fabricate three test PCBs. First, the capacitor plates were etched in the FaradFlex® copper coating and the copper surface was developed in an oxidation process. Then, the structure consisting of the bottom FR4 substrate, 2 × 106 prepreg, the FaradFlex® foil, the second layer of 2 × 106 prepreg and the top FR4 was stacked and laminated at the pressure of 3 MPa and temperature...
of 180 °C. Afterwards, the holes were drilled and plated and the outer copper layer was etched and gold plated to form the contacts to the embedded capacitors.

Each PCB consisted of nine identical coupons (Fig. 1a) which were then separated, however, marks on the coupons allowed us to determine their original position on the PCB.

Each coupon consisted of several test structures with different sizes. The dimensions of the test structures are shown in Fig. 1b. The 5 × 5, 10 × 2.5 and 2.5 × 10 structures had the same area but different aspect ratios, which might have the influence on the capacitor electric properties.

The impedance spectra were measured using Agilent 4294A impedance analyser in the frequency range of 1 kHz to 110 MHz with dedicated high-frequency electrode system. The electrode system had minimised parasitic elements (C < 30 fF, L < 8 nH, R < 30 mΩ) and was designed in a way allowing us to perform a complete leads compensation procedure in the impedance analyser. The measurement of impedance spectra was controlled by the home-built software, Impedancer [8]. The spectra were presented and analysed using Scribner ZView®. The measurements of temperature dependence were conducted on the water-cooled Peltier stage with PID temperature controller.

After the initial measurement, the coupons were divided into two batches and subjected to two different accelerated ageing processes:

Process 1: 150 h at 60 °C, 95 % RH
Process 2: 150 h at 140 °C

After the accelerated ageing processes, the test structures were measured again.

3. Results

3.1. Impedance measurements and equivalent circuit analysis

Exemplary impedance spectra of embedded capacitors, measured at room temperature, are shown in Fig. 2.

All samples exhibited capacitive character of impedance in the whole frequency range except for the largest capacitor where, in spite of using low-inductance electrodes system, the self-resonance was observed.

The plot of equivalent parallel capacitances and loss factors for similar BC12TM and BC24M samples (Fig. 3) indicated the decrease of capacitance with increasing frequency, which is well described in equivalent circuit modelling by using constant phase elements [4] in situations where electrodes