Development of a Low-ESR Functional Polymer Tantalum Capacitor, the “NeoCapacitor”

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Abstract

NeoCapacitor is the name given to tantalum capacitors using conductive polymer materials. In order to meet speed increase trends, power consumption reduction and drive voltage reduction of CPUs, NEC TOKIN has released various V-sized low-ESR products of up to 9mΩ and it is continuing to develop products with lower ESR values. Recently NEC TOKIN succeeded in developing its most advanced 6mΩ product so far by improving the capacitor device structure and cathode layer to meet the latest market requirements.

Keywords

tantalum capacitor, low ESR, conductive polymer

1. Introduction

Recent increases in speed and decreases in the power consumption and drive voltages of CPUs have accelerated the need for capacitors for use in decoupling to have lower ESR (Equivalent Series Resistance) values. NeoCapacitors are tantalum capacitors that use a conductive polymer material. The use of a polymer with a higher conductance than the previous manganese dioxide material significantly reduces the ESR and thereby meets the requirements outlined above. NEC Tokin has developed capacitors with ESRs as low as 9mΩ and maximum dimensions of 7.3mm (L) × 4.3mm (W) × 2.0mm (H) (V-size) [1)]. In order to respond to the latest market requirement further, we have recently succeeded in developing very advanced, 6mΩ capacitors by improving the capacitor device structure and part of the cathode layer. This paper provides details of our achievements.

2. Outline of the NeoCapacitor Product

Thanks to its higher capacitance per volume the tantalum capacitor is in general regarded among the various capacitors as being suitable for compact, slim devices with large capacity requirements. NeoCapacitor products offer a low ESR value while also inheriting the technology of size reduction and capacity increase of the tantalum capacitors. **Fig. 1** is a schematic representation of a NeoCapacitor that depicts an external view of a typical product (**Photo**).

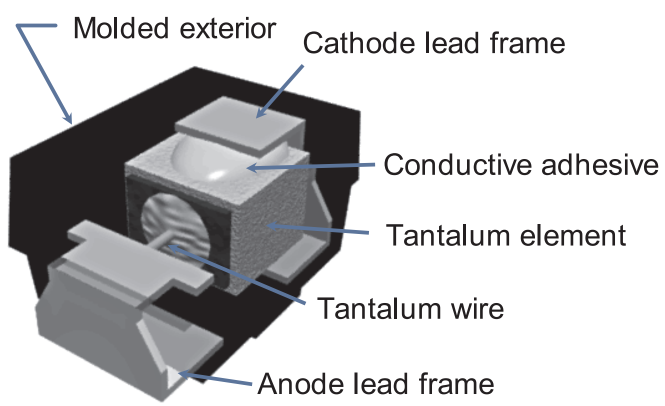

Fig. 1 Structure of NeoCapacitor.

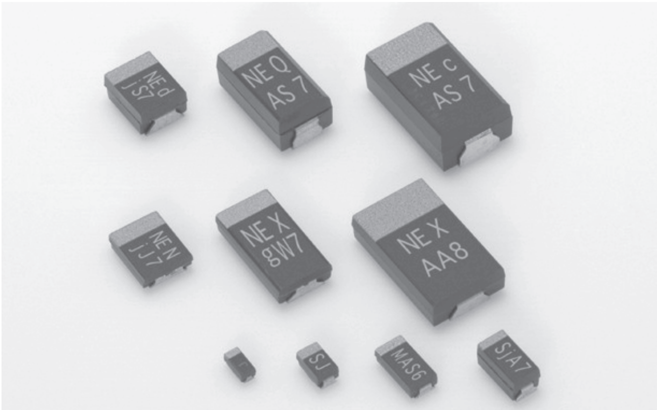

Photo External view of a NeoCapacitor product.

The NeoCapacitor is fabricated using the processes summarized in the following: Tantalum powder of submicron size is subjected first to press molding together with the tantalum wire, and then to vacuum high-temperature sintering at around 1,500°C in order to form a pellet (anode body). Next, an inductive film (Ta_2O_5) is formed on the surface of the obtained porous pellet by means of an anode oxidation process; conductive polymer is deposited as a solid electrolyte both inside and outside the pellet. Graphite and silver paste layers are sequentially deposited as the cathode lead and the capacitor element are formed. Next, the external anode/cathode terminals are attached to the element, the exterior is finished by epoxy resin molding, and the NeoCapacitor device is completed after undergoing ageing and electrical characteristic testing.

3. Approaches to Development

In this section we will discuss the ESR values of tantalum capacitors that are composed of the following components:

1) R_f : Virtual ESR component of the tantalum oxide film and interfacial absorption molecules.

2) R_0 : Component associated with the distributed constant resistance, varying according to the specific resistance of the solid electrolyte and the shape of the pellet pores.

3) R_{ex} : Contact resistance of the solid electrolyte, graphite, silver paste and lead terminals on the external surface, plus the intrinsic resistivity values of the materials.Based on these components, the ESR value may be expressed as follows:

$ESR=R_f+R_0+R_{ex}$

When the above formula is rewritten to express the ESR as a function of frequency:

$ESR(\omega)=R_f(\omega)+R_0(\omega)+R_{ex}$

$=\tan\delta_f/\omega C_f+R_0(\omega)+R_{ex}$

Here, C_f and $\tan\delta_f$ are respectively the capacitance and dielectric tangent of the tantalum oxide film, and $R_f(\omega)$ decreases in inverse proportion to the frequency. On the other hand, $R_0(\omega)$ presents a constant value in the low-frequency domain and is decreased in inverse proportion to the root of the frequency in the high-frequency domain. R_{ex} is always constant independently of the frequency. **Fig. 2** shows a schematic representation of the frequency characteristics of the ESR.

In order to promote a reduction in ESR value of the NeoCapacitor, we analyzed the existing products. **Fig. 3** shows the change in ESR before and after the reflow of an existing

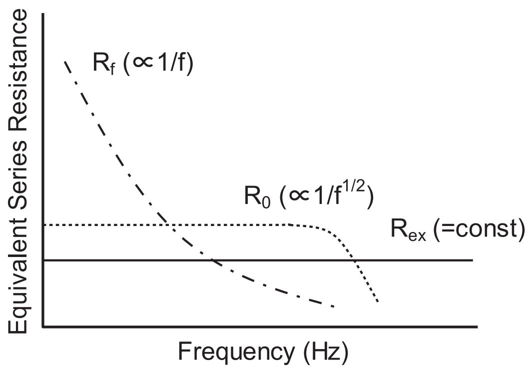

Fig. 2 ESR frequency characteristics.

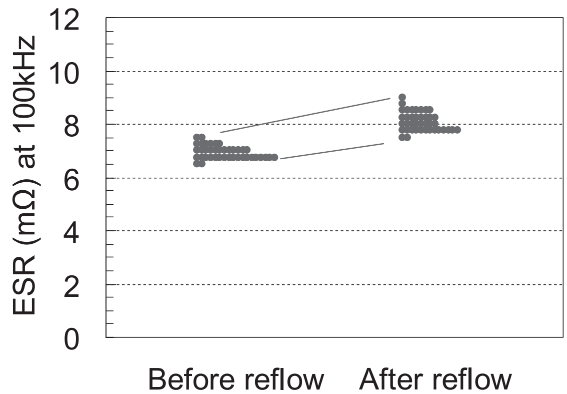

Fig. 3 ESR change of existing products before and after reflow.

V-sized product with 2.5V rated voltage, 330μF rated capacitance and ESR of no more than 9mΩ. This result shows that a capacitor with an ultra low ESR of the 6mΩ class necessitates the following two approaches:

1) Reduction of intrinsic ESR of the product before reflow;

2) Reduction of changes in ESR values due to reflow performed in the fabrication process.

In the two approaches above, it is already known that the main point in 1) is the resistance derived from the NeoCapacitor product structure, and that in 2) is the resistance derived from the cathode layer composed of conductive polymer, graphite and silver.

In terms of the components of the ESR described above, 1) corresponds to R_{ex} and 2) corresponds to R_0 and R_{ex} . We therefore proceeded to the recent developments by focusing on these two points.

4. Study of the Structural Implications of ESR Value Reduction

In order to reduce the resistance derived from the NeoCapacitor product structure, we made observations of the tantalum wire leading out of the tantalum element. **Fig. 4** shows the relationship between the tantalum wire diameter of a V-sized capacitor and the ESR values of the nearby region. As the ESR is roughly in inverse proportion to the surface area of the tantalum wire, it is effective to increase the tantalum wire diameter in order to reduce the ESR value. Previous V-sized products with 9mΩ ESR used a tantalum wire with a diameter of 0.49mm, in this context we studied the use of tantalum wire with a diameter of 0.8mm for the development of the 6mΩ ESR products. Nevertheless, as the thickness of the tantalum element in the V-sized product is only 0.84mm, it is hard to embed the 0.8mm tantalum wire directly. Therefore, we decided to deform a 0.8mm tantalum wire into a flat wire of 0.35mm thickness and 1.4mm width and embed it in the tantalum element. This strategy has made it possible to use a thicker tantalum wire with V-sized tantalum devices and to reduce the ESR values as influenced by the tantalum wire by 0.9mΩ.

The flat deformation of the tantalum wire has also made it possible to reduce the ESR values at the following two points as well as to reduce the ESR of the tantalum wire itself.

1) ESR reduction thanks to the increase in the connection area between the tantalum wire and the anode lead frame: 0.5 mΩ.

2) ESR reduction thanks to the increase in the connection area between the tantalum wire and the tantalum element: 0.4 mΩ.

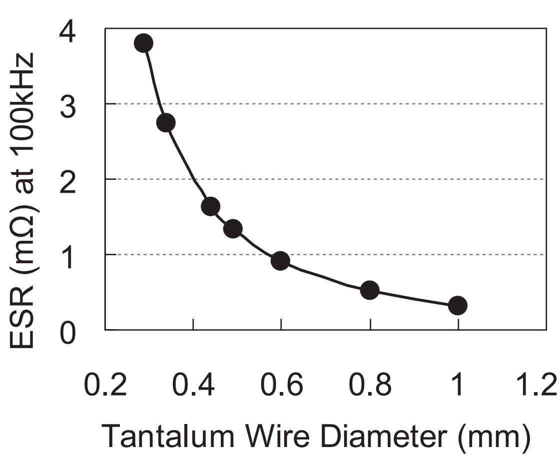

Fig. 4 Correlation between tantalum wire diameter and ESR.

As a result, the change of the tantalum wire diameter from 0.49mm to 0.8mm has enabled a reduction of the intrinsic ESR value of the product by 1.8mΩ in total.

5. Reduction of the Cathode Layer ESR Value

Next, we attempted to reduce the changes in the ESR values due to the reflow operation in the fabrication process by reducing the resistance derived from the cathode layer. We established the following inferences on the cause of the ESR value changes resulting from the reflow:

1) High temperatures of around 240°C applied during reflow may be a cause of slight deformations such as deviation and distortion of the mold resin used in the external finish.

2) The deformation of the mold resin imposes a physical stress on the cathode layer and causes separations inside the conductive polymer layer, between the conductive polymer and graphite layers and between the tantalum oxide film and conductive polymer layer, etc.,

3) Such separations cause resistance in the cathode layer and contact resistances between the layers.

In the course of the present development we selected those controlling factors that might be able to reduce the separation of the cathode layer and to thereby reduce changes in the ESR values and established a test plan by utilizing L18 test for the 8 control factors of the quality engineering standards.

As a result of the test, we confirmed that 4 of the 8 factors are effective for preventing separation of the cathode layer. These include Factor a (Tantalum powder type), Factor b (Conductive polymer formation process), Factor c (Conductive polymer formation count) and Factor d (Graphite paste amount). **Fig. 5** shows the change in the ESR values in the fabrication process when the 4 factors defined above are modified with a pellet using a 0.8mm tantalum wire fabricated as described in the previous section. According to the figure, the ESR change due to reflow is reduced to around 0.4mΩ, in contrast with the 1.2mΩ approx. of the 9mΩ product that is shown in Fig. 3.

The ESR reduction effect obtained by the modifications of the 4 factors defined above can be considered as follows:

Factor a: The tantalum powder type is modified to increase the pores on the pellet surface and provide an anchor effect between the oxide film and conductive polymer layer.

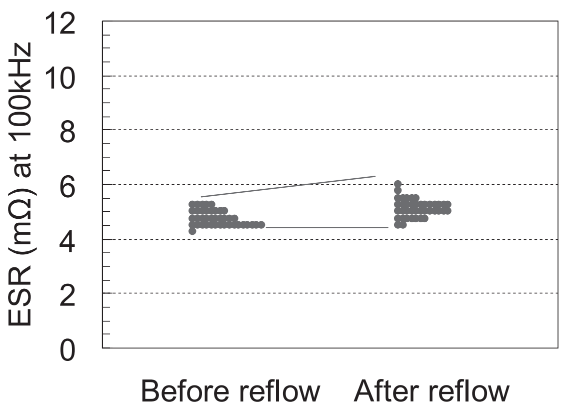

Fig. 5 ESR change during the production process of newly developed 6mΩ capacitors.

Factors b, c: The conductive polymer formation process is modified to efficiently form a layer inside the pores on the pellet surface and to increase its adherence to the oxide film.

Factor d: The graphite paste is diluted to improve permeation into the conductive polymer layer and to increase its adherence to the graphite layer. The resulting decrease in the amount of adhesion also makes the graphite film thinner and thereby reduces its resistance.

6. Conclusion

As a result of the improved resistance characteristics brought about by changes in the design of the product structure and modifications to the cathode layer as described above, we were able to develop V-sized products with 6mΩ ESR, 2.5V rated voltage and 330μF rated capacitance. The ESR frequency characteristics of the products are shown in **Fig. 6** .

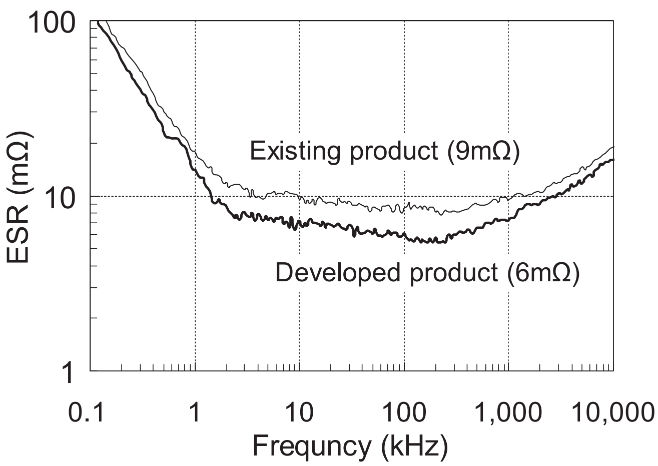

Fig. 6 ESR frequency characteristic.

The newly developed 6mΩ products have expanded the line of the PS/G series capacitors that are marketed as products with ultra low-ESR of no more than 9mΩ (**Table** shows the product line of the PS/G Series).

In the future, we are planning to develop products with an ESR of 5mΩ or less as shown in **Fig. 7** , as well as compact B2-sized products that feature maximum dimensions of 3.5mm (L) × 2.8mm (W) × 2.1mm (H).

Table PS/G series V-sized NeoCapacitor: Products with the ultra low ESR.

Capacitance (μF)	ESR (mΩ) at 100kHz		
	9	7	6
220	○	○	△
330	○	○	○
470	○	○	△

○ : Already developed
△ : Under development

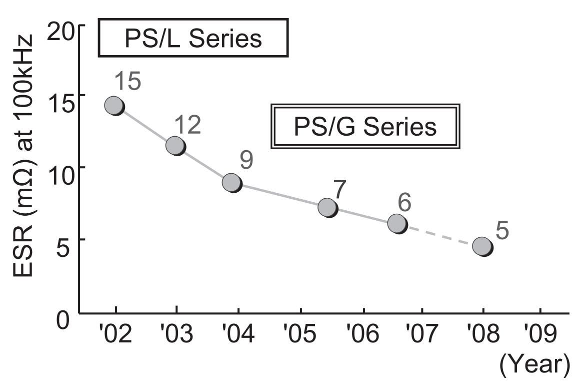

Fig. 7 Development roadmap of low-ESR NeoCapacitor products.

Reference

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