Next Generation of Polymer Capacitors:

Boosting Performance of Electrolytic Capacitors with Conductive Polymer Dispersions

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Abstract

The major use of polymer aluminum and tantalum capacitors is for low voltage consumer electronics. The development of conductive polymer dispersions has extended the voltage range of polymer capacitors up to 125 V in the last years and opened the door for high reliability applications like automotive. We present the next generation of polymer aluminum capacitors reaching rated voltage of 400 V. Life-test, frequency and low temperature characteristics are reported.

Introduction

For more than 20 years, applications of polymer aluminum and tantalum capacitors have been driven by low ESR requirements [1]. Traditional electrolytic capacitors were not able to meet these requirements of modern electronic circuits like motherboards. However, the application field of polymer capacitors was limited to consumer electronics mainly due to the lack of high voltage capability, relatively high DC leakage current (DCL) and low reliability performance.

During the last decade, these restrictions of polymer capacitors have been overcome and high voltage, low DCL and high reliability applications could be accessed. The rated voltage range of polymer capacitors has been extended from maximum of about 25 V to 125 V [2]. In combination with a superior DCL performance, the new polymer capacitors have been introduced in high reliability applications like automotive. Today, polymer capacitors are even promoted for space applications which was unimaginable some years ago [3,4]. Low ESR and high ripple current capability allow to downsize electronic circuits by using smaller capacitors or by replacing a number of bulky electrolytic capacitors with a single polymer capacitor.

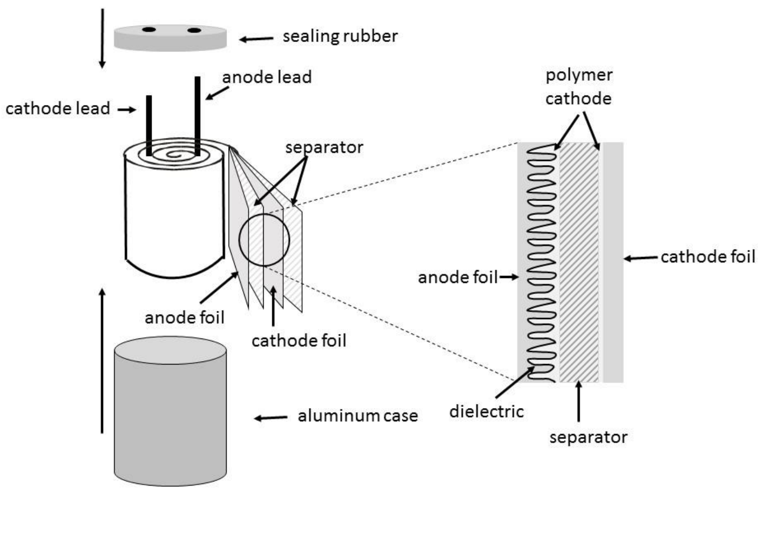

Fig. 1: Structure of an aluminum polymer capacitor (winding type).

The technology move to high voltage, low DCL and high reliability was enabled by the development of new conductive polymers for capacitor applications [5]. Conductive polymers are used as cathode material in polymer capacitors (Fig. 1). A conductive polymer film is deposited on the dielectric which was formed by anodization of a porous aluminum or tantalum electrode. For a long time, chemical in-situ polymerization methods had to be applied to form such a conductive polymer cathode film. Precursors of conductive polymers, monomer and oxidizer, are introduced into the porous capacitor body and the cathode is formed by a chemical reaction within the device. The development of conductive polymer dispersions for capacitor applications allows for a direct deposition of the conductive polymers without any chemical in-situ reaction (Fig. 2). Thus, the manufacturing process of polymer capacitors is simplified significantly: instead of controlling chemical reactions in millions of small devices, a simple dip and dry coating process is applied.

Conductive Polymer Dispersions

During the material development, it was discovered that conductive polymer dispersions have a huge impact on the voltage performance of the capacitor [6]: The break-down voltage of the dielectric is not affected by the deposition of a conductive polymer film made from dispersions. On the contrary, in-situ deposition of the conductive polymer degrades the voltage resistance of the dielectric layer to a level where the device is short circuited. Only by a reformation or ageing process, the dielectric performance can be restored. However, such restoration hardly achieves the initial break-down properties of the dielectric. Especially for rated voltages higher than 10 V, the gap between the break-down voltage of the polymer capacitor and the anodization voltage of the dielectric gets wider with increasing anodization voltage.

The different performance of in-situ polymerization and polymer dispersions is attributed to the particle nature of the polymer dispersions. Especially for higher anodization voltages, i.e. thicker dielectrics, the quality of the dielectric suffers. Molecules used for in-situ polymerization can access pin-holes in the dielectric. The resulting conductive polymer film after polymerization reduces the break-down strength of the dielectric. The conductive polymer in dispersions forms particles larger than 10 nm (Fig. 2). Such particles cannot enter small pin-holes and the break-down strength of the dielectric is not deteriorated.

Voltage Limitation

The question arises where the voltage limits of this new technology are. Can polymer dispersions allow to extend the voltage range of polymer capacitors beyond 125 V? Can polymer capacitors be used at the input side of voltage converters (250-450 V) or be applied in the high voltage circuits of electric cars or new energy (up to 750 V)?

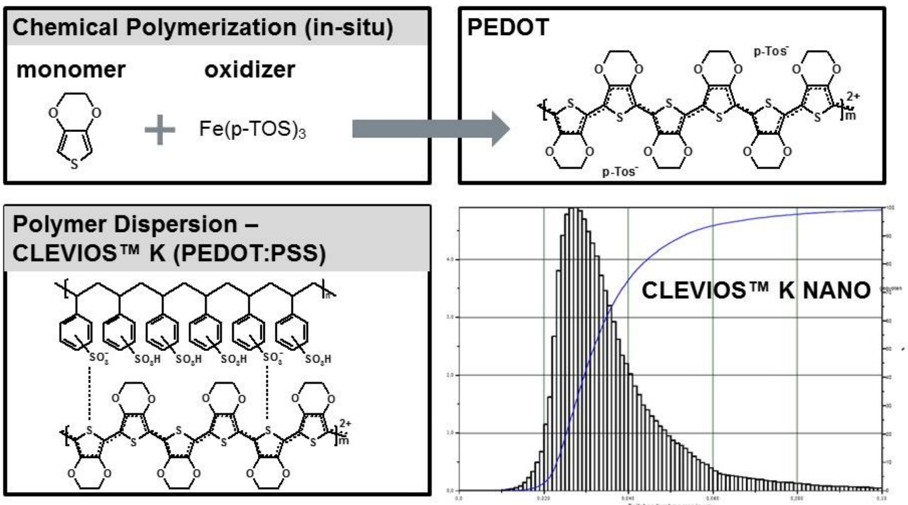

Fig. 2: PEDOT conductive polymer: chemical polymerization (upper) and polymer dispersion (lower).

Anodization voltage [V]	Break-down voltage [V]
335	399
469	492

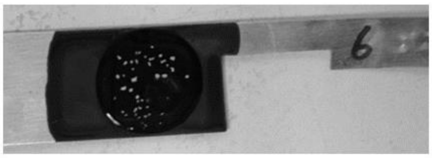

Table 1 and Fig. 3: Results and coated aluminum foil for break-down experiment.

We designed an experiment to evaluate the principle voltage limits of polymer dispersions. Plain aluminum foils anodized at different voltages were coated with Clevios™ K, a PEDOT:PSS polymer dispersions from Heraeus. Corners and edges of the aluminum foil were covered with an insulating lacquer before conductive polymer deposition in order to avoid any impact of low quality dielectric at these parts of the foil (Fig. 3). The positive voltage output of a power supply was contacted to part of the aluminum foil which was not anodized. The negative output was connected to a soft spring-loaded gold contact which was brought into direct contact with the conductive polymer coating. The voltage of the power supply was ramped up until electrical break-down was observed. The break-down voltage even surpassed the anodization voltage of the highest anodized foil (469 V) which was available to us (Table 1). This simple experiment proofs that there is currently no limitation given by the conductive polymer to realize break-down voltages up to about 500 V.

Of course, a capacitor design is more sophisticated than our simple experiment. Any defect induced in the dielectric during manufacturing potentially limits the voltage performance.

400V Polymer Capacitors

Zhaoqing Beryl Electronic Technology Co., Ltd. succeeded to develop 400 V polymer capacitors using a Clevios™ K conductive polymer dispersion from Heraeus in 2016 [7]. Meanwhile, Beryl released a set of 400 V low impedance, high ripple current capacitors (GN series, Table 2, Fig. 4).The capacitors are rated for 2000 hours at 125°C and are RoHS (Restriction of Hazardous Substances) compliant. Load life test results at 125°C are shown in Fig. 5.

The frequency response of the polymer capacitors is significantly improved when compared to electrolytic capacitors (Fig. 6). Due to the high conductivity of the conductive polymer, the polymer capacitors have not only a much lower ESR, but exhibit stable capacitance and dissipation factor at high frequencies.

Rated Voltage (V)	Rated Capacitance (μF)	Case Size ΦD×L (mm)	Tan δ (120Hz)	ESR(Ω) at 20℃, 100kHz	Rated Ripple Current (mArms/105℃ /100kHz)	Rated Ripple Current (mArms/125℃ /100kHz)
400 V (2G)	2.2	8*8	0.15	1.2	106	61
	3.3	10*12	0.15	0.9	204	118
	4.7	10*20	0.15	0.4	260	150
	10	13*20	0.15	0.3	753	435

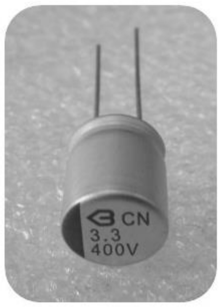

Table 2 and Fig. 4: Beryl's 400 V polymer capacitor CN series.

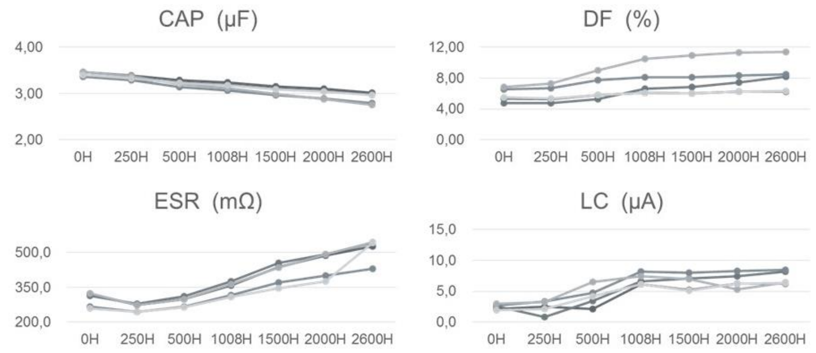

Fig 5: 125°C load life test for 3.3μF/400V ф 10×12L polymer capacitors, capacitance at 120 Hz (upper left), ESR at 100 kHz (lower left), dissipation factor at 120 Hz (upper right) and DC leakage current at 400 V (lower right).

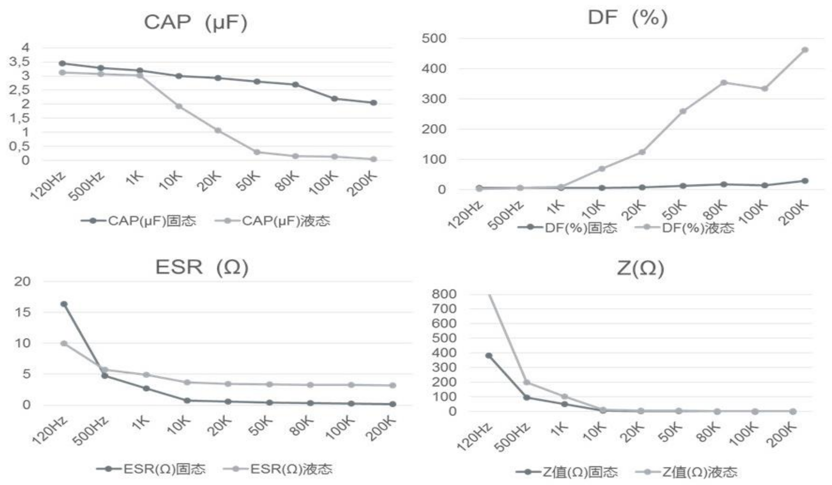

Fig 6: Comparison of frequency characteristic for 3.3μF/400V ф 10 × 12L polymer (black) and electrolytic (grey) capacitors, capacitance at 120 Hz (upper left), ESR at 100 kHz (lower left), dissipation factor at 120 Hz (upper right) and impedance at 100 kHz (lower right).

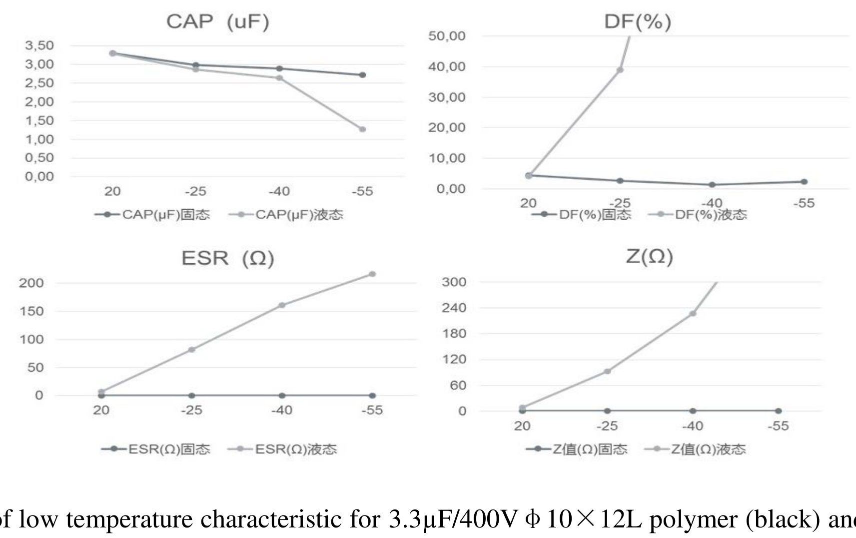

Fig 7: Comparison of low temperature characteristic for 3.3μF/400V ф 10 × 12L polymer (black) and electrolytic (grey) capacitors, capacitance at 120 Hz (upper left), ESR at 100 kHz (lower left), dissipation factor at 120 Hz (upper right) and impedance at 100 kHz (lower right).

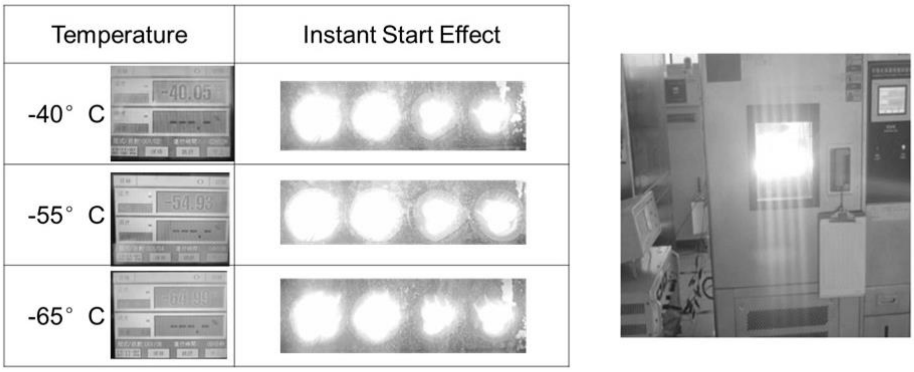

Fig. 8: Powering-on of LED lights at different low temperatures using polymer capacitors in LED power circuit.

At low temperatures, the performance of electrolytic capacitors suffers. Ion-mobility of the electrolyte is significantly reduced at low temperature. Therefore, ESR, dissipation factor and impedance increase and capacitance is reduced. Such properties limit the usage and the efficiency of electrolytic capacitors for low temperature applications like outdoor LED lighting. Beryl’s 400 V polymer capacitors provide stable characteristics even at low temperature (Fig. 7). Powering LED lights at temperatures down to -65°C is feasible with those capacitors (Fig. 8).

Conclusion

Clevios™ K conductive polymer dispersions of Heraeus allow to expand the application of polymer capacitors to a voltage regime of at least 400 V. Zhaoqing Beryl has successfully developed 400 V aluminum polymer capacitors. The high voltage polymer capacitors outperform electrolytic capacitors with respect to ESR, frequency response and ripple current. Together with the stable low temperature characteristic and the inherent prevention of dry-out by using a solid conductive polymer, such high voltage polymer capacitors are able to meet the requirements of modern electronics.

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