 DOI:10.30420/566414097

Aging Behavior at 85°C and 85% RH of High Heat Capacitors for DC-Link Applications

Adel Bastawros[1], Tetsuya Motohashi[2], Koichi Nakashima[2], Takamune Sugawara[2], Hisao Katsuta[2], and Yuan Zhou[3]
[1] SABIC, USA
[2] SABIC, Japan
[3] SABIC, China

Corresponding author: Adel Bastawros, Adel.Bastawros@SABIC.com

Speaker: Yuan Zhou, Yuan.Zhou@SABIC.com

Abstract

Aging behavior of new generation capacitors intended for use at high temperatures in AC-DC inverter applications have been evaluated under damp heat conditions (85°C and 85% relative humidity (RH)) and applied voltage for a minimum of 1000 hours of aging.
Two capacitor designs were tested, using 3µm and 5µm ELCRES™ HTV150A high-heat films, respectively. Test voltages were 0, 300 and 500 volts for the capacitors made with 3µm film and 0, 500 and 800 volts for the capacitors made with 5µm film. Capacitance change (ΔC), dissipation losses (tan δ) and insulation resistance (IR) were tracked as indicators of aging performance.

For both designs, ΔC, tan δ and IR showed stable response with little or no change over the 1000-hour test duration required by industry standards. Tan δ and IR were independent of the applied voltage level. The change in capacitance (ΔC) showed a slight increase (gain) of 1~2% with applied voltage.
Damp heat aging was extended beyond industry requirement to reach 2000 hours for capacitors made with 5µm film and 1750 hours for capacitors made with 3µm film; ΔC, tan δ and IR remained acceptable.

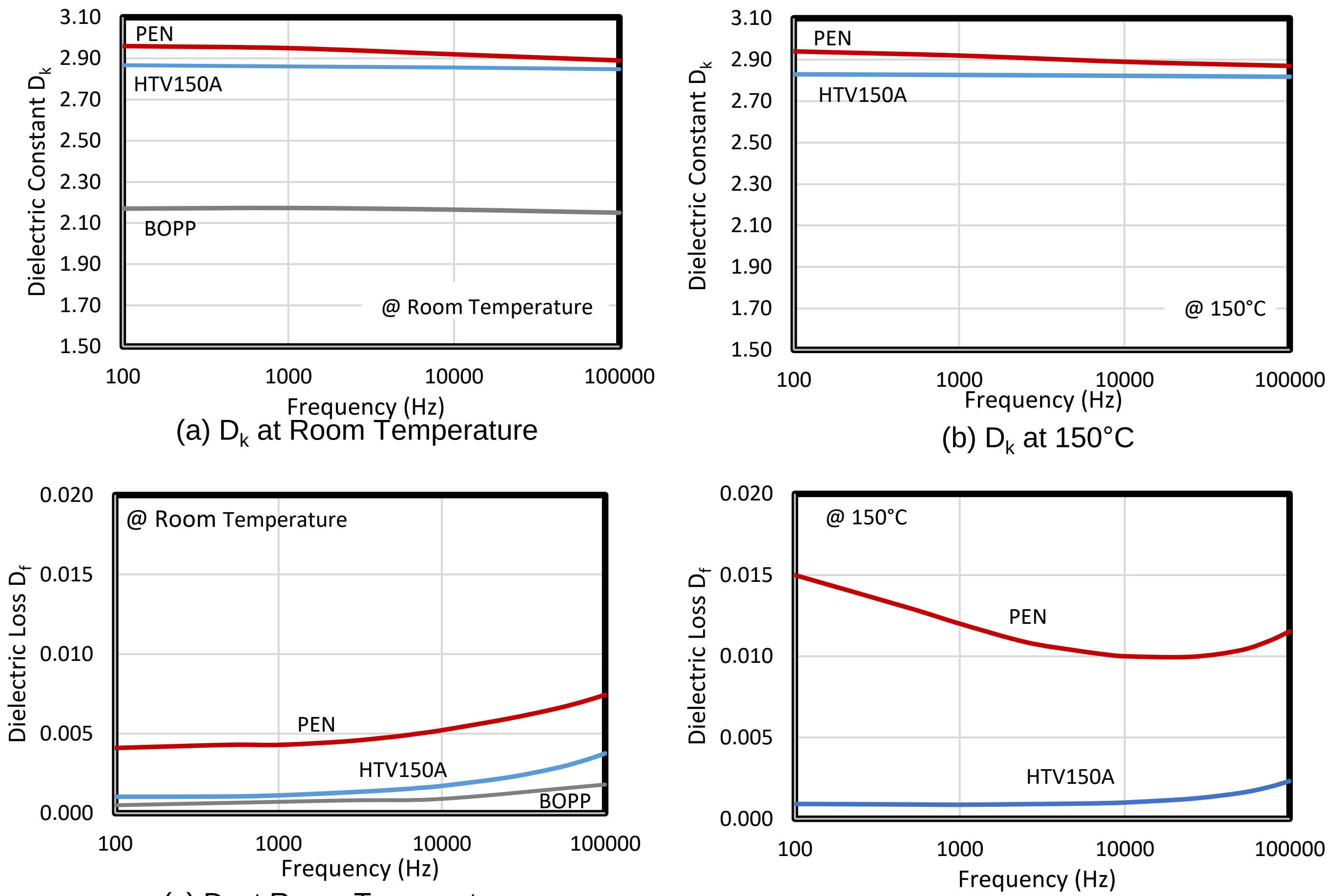
Meeting industry requirements for damp heat performance on the component level increases the confidence in employing the high heat capacitors in incumbent and new AC-DC inverter designs for the DC-Link in electric vehicles.

1 Introduction

Aging performance of power electronics systems, such as DC-Link inverter modules in electric vehicle applications, is key for reliable extended operation of the entire system. Such performance is typically evaluated by means of accelerated reliability testing of the whole system. Although the architecture of the entire system with all its assembled components is what determines the system performance; reliability testing on the individual component level could provide early indications of impact on the whole system behavior when a new component is used in an existing or new module design. Capacitors are an example of passive components in inverter modules that receive considerable reliability testing on the component level.
Adoption of SiC technology in AC-DC inverter modules in electric vehicles has signified the need for capacitors that can operate at higher temperatures reaching 150°C. Operating at higher temperatures beyond the limits of incumbent film materials, such as BOPP (biaxially oriented polypropylene) or PEN (polyethylene naphthalate), has been an ongoing industry and academic challenge [1,2,3].

SABIC has been developing new materials for use as ultra-thin film in dielectric applications with operating temperatures upwards of 150°C [4]. A recently introduced film grade, ELCRES™ HTV150A, was engineered to provide a new generation of ultra-thin dielectric films and offer a different solution to meet the need for high temperature capacitor films [5].

Fig.1 shows the dielectric constant D_k at room temperature (a) and at 150°C (b) as a function of frequency. HTV150A has a D_k of 2.9 that is very stable over the temperature range.



(a) D_k at Room Temperature

(b) D_k at 150°C

(c) D_f at Room Temperature

(d) D_f at 150°C

Fig. 1 Dielectric constant (D_k) and dielectric loss (D_f) for HTV150A film

By comparison, PEN has similar D_k performance whereas BOPP is 30% lower. At 150°C, HTV150A and PEN retain their D_k performance. BOPP has no D_k value at 150°C.

Fig. 1 (c and d) shows dissipation losses represented by D_f, at room temperature and 150°C, respectively. Dissipation losses are lower for HTV150A film vs PEN at room temperature. At 150°C HTV150A film maintains stable performance, whereas losses in PEN increase. The increased losses limit use of PEN films beyond 125°C. BOPP has low losses at low temperatures but cannot survive higher temperature levels.

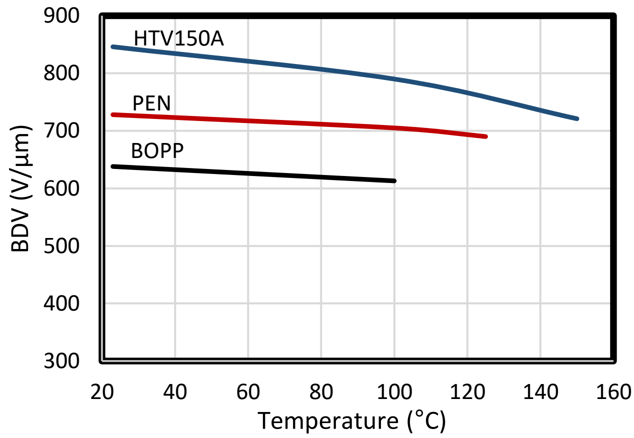


Fig. 2 Breakdown voltage (V/µm)

Breakdown voltage (BDV) is measured according to ASTM D149 on unmetallized film. Fig. 2 shows HTV150A film having a highest BDV of about 850 V/µm at room temperature and 720 V/µm at 150°C. PEN and BOPP have lower values; noting that no value exists for BOPP at 150°C and the test for PEN is performed up to 125°C since losses limit use of PEN at higher temperatures.

The base resin in HTV150A film is an amorphous engineering thermoplastic resin with high glass transition temperature (T_g) of 205°C and relatively stable loss factor (D_f) at temperatures up to 150°C, avoiding the issues seen in some crystalline resins where the loss factor can change significantly at higher temperatures, or at temperatures near the glass transition temperature of the material. The

 DOI:10.30420/566414097

polymer's aromatic carbon/aliphatic carbon ratio and net polarizability are balanced to deliver a higher dielectric constant than conventional BOPP while maintaining adequate self-clearing for many high voltage applications [6].

In the current work, high heat capacitors made with HTV150A film are tested against damp heat aging requirements for the AC-DC inverter modules. Meeting industry requirements on the component level increases the confidence in employing the capacitors in existing AC-DC inverter designs that already meet the requirements. The damp heat performance demonstrated here also supports implementation of the high-heat capacitors in new demanding module designs (e.g., SiC based modules) that would benefit from using high-heat components.

2 Experimental

In the current work, damp heat aging behavior of new generation high-heat capacitors is evaluated. Damp heat testing is performed according to AEC-Q200 (REV D) standard published by JEITA (Japan Electronic Information Technology Association). In this test, powered capacitors are aged in a humidity-controlled chamber at temperature of 85°C and 85% relative humidity for a minimum of 1000 hours.

2.1 Test capacitors

Metallized HTV150A films of 3μ and 5μm thicknesses were used to build two groups of capacitors for testing. A segmented metallization pattern was applied to rolls of film at Machine Technologies Co., Ltd. (Japan). Film width was 30mm with resistivity of 20 Ω/sq on an aluminum body and 5 Ω/sq on a zinc heavy edge, Fig.3.

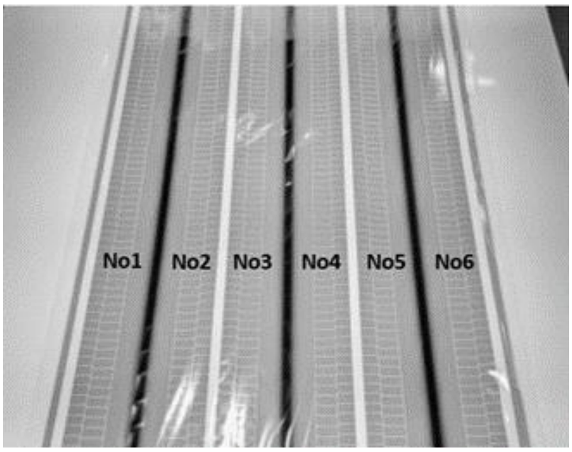


Fig. 3 Segmented metallization on HTV150A film

Pairs of film were wound into round capacitors that were later flattened to an oval geometry for a better shape factor. Zinc thermal spray was applied to both ends of the flattened elements, followed by terminal soldering for electrical connectivity. The elements were placed in a PPS casing and potted with a high temperature thermoset epoxy resin to provide the test capacitors, Fig. 4. Design capacitance was 5μF for 5μm film capacitors and 10μF for 3μm film capacitors.

2.2 Aging Test

Damp heat exposure was done on powered test capacitors in a controlled environmental chamber (ESPEC, PSL-2J) set to 85°C and 85% relative humidity, Fig. 5. A group of 6 identical capacitors was used for each test condition.

Throughout the exposure DC voltage was applied by external power supplies; TEXIO, PA600 and Matsusada HJPM series. Three voltage levels were applied to each group during aging: 0, 300 and 500 volts for capacitors with 3μm film, and 0, 500 and 800 volts for the capacitors with 5μm film. The maximum applied voltage is consistent with target operating voltages for the two dominant segments of AC-DC inverters for EV applications: namely, the 500- and 800-volt segments.
Capacitance change (ΔC), dissipation losses (tanδ) and insulation resistance (IR) were tracked throughout the test as indicators of aging performance. Capacitance change (ΔC), dissipation losses (tan δ) were measured with an LCR meter (Keysight Technology, E4980A) at 1kHz frequency. IR was measured with an IR meter (HIOKI, SM-8220).

Fig. 4 Test capacitor made with HTV150A film

ISBN 978-3-8007-6414-3

 DOI:10.30420/566414097

Fig. 5 Controlled environmental test chamber

For IR measurements the capacitors were briefly removed from the chamber, stabilized and returned to the chamber after measuring.

3 Capacitor Aging Behaviour

Aging test results are depicted in Fig. 6 for the 5µm film capacitors and in Fig. 7 for the 3µ film capacitors.

Fig. 6(a) shows stable capacitance over 1000 hours of aging. The graphs are the averages for 6 test capacitors. Change in capacitance ΔC/C (%) shown in Fig. 6(b) increased slightly over time with highest increase of about 2% at 800V. Capacitance gain is typically caused by additional tightening of the winding element when thermal stress is applied. However, it is not clear why higher voltage would induce additional tightening. Nevertheless, the 1~2% of change remains a harmless gain.

Fig. 6(c) shows stable average dielectric losses, tan δ, of only 0.0015. The losses were the same at the 0, 500 and 800V applied voltages.

Similarly, insulation resistance IR remained stable and unaffected by applied voltage.

Encouraging stable results up to 1000 hours of aging, inspired extension of the test to 2000 hours of aging. At 2000 hours ΔC/C (%), tan δ, and IR remained stable, thus exceeding industry minimum requirement.

Capacitance for 3µm film capacitors remained stable over 1000 hours of damp heat aging, Fig. 7(a). A harmless gain of ~2% in capacitance at the highest voltage level (500V) was also present here, Fig. 5(b). Dielectric losses (tan δ) and insulation resistance (IR) remained stable as shown in Figs. 7(c) and 7(d), respectively.

Like 5µm capacitors, aging time was extended to 2000 hours. At 0 and 300V, performance remained stable up to 2000 hours. However, at the highest applied voltage (500V), stable performance continued until 1750 of aging; still far exceeding the 1000 hour minimum required by the industry.

The demonstrated stable capacitor performance for both gauges exceeds damp heat test requirements per AEC-Q200 standard.

4 Conclusions

High-heat capacitors made with 3µm and 5µm HTV150A film pass and exceed 1000-hour aging test at 85°C and 85%RH. Capacitance change, dielectric losses and insulation resistance had little or no change over the duration of the test when 0, 300 and 500 volts were applied to the 3µm film capacitors and when 0, 500 and 800 volts were applied to the 5µm film capacitors. The stable performance continued during additional aging, beyond what is required by the industry, reaching 2000 hours for the 5µ film capacitors and 1750 hours for the 3µm film capacitors.

Meeting industry requirements on the component level increases the confidence in employing the high-heat capacitors in existing AC-DC inverter designs that already meet the requirements. The damp heat performance demonstrated here supports implementation of the high-heat capacitors in new demanding module designs using SiC technology.

5 Acknowledgements

The authors are indebted to SABIC's Global Technology Teams for valuable insights on capacitor testing and film characterization. Special thanks to Machine Technologies for assistance with metallization and building of test capacitors.

6 References

[1] L. Caliari, P. Bettacchi, E. Boni, D. Montanari, A. Gamberini, L. Barbieri, and F. Bergamaschi, "KEMET film capacitors for high

ISBN 978-3-8007-6414-3

 DOI:10.30420/566414097

temperature, high voltage and high current”. Capacitor and Resistor Technology Symposium (CARTS) International Proc. ECA (Electronics Components, Assemblies & Materials Association), pp. 1-15, 2013.

[2] I. W. Clelland and R. A. Price, “Polymer Film Capacitors”, APEC 2011, Special Session 1.3.4, pp. 2-4, 2011.

[3] D. Tan, L. Zhang, Q. Chen, et al, “High-Temperature Capacitor Polymer Films”. Journal of Electronic Materials, Vol. 43, 4569–4575, 2014.

[4] N. Pfeiffenberger, F. Milandou, and M. Niemeyer, “High Temperature Polyetherimide Film Development,” IEEE Trans. Dielectrics and Electrical Insulation Vol. 25, No. 1, pp 120-126, 2018.

[5] A. Bastawros, A. Pingitore, J. Mahood, M. Niemeyer, F. Yu and T. Sugawara, "New Generation Capacitor Films for 150°C High Voltage AC-DC Inverter Applications," PCIM Europe 2022, pp. 1517-1523, 2022.

[6] A. Bastawros, A. Pingitore, C. Grabowski, P. Flanagan, and M. Buratto, "High Temperature Capacitor Films with Reduced Dissipation Losses for High Voltage AC-DC Inverters," proc. PCIM Europe 2023, pp. 1314-1317, 2023.

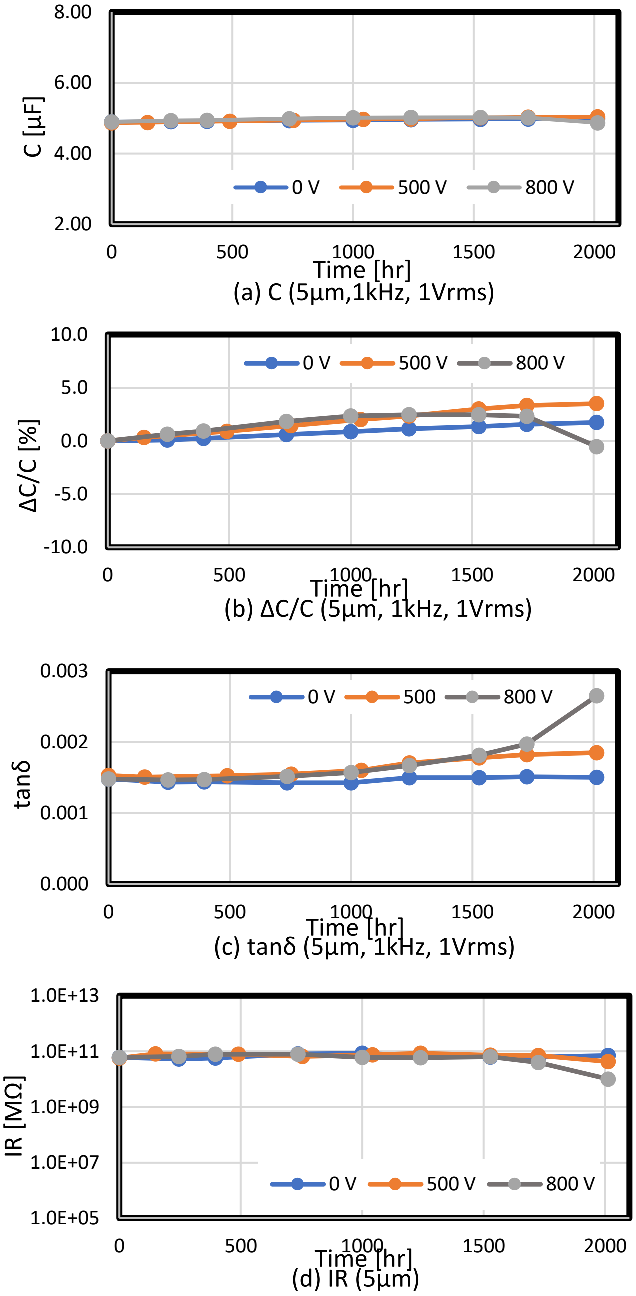


Fig. 6 Aging Test for 5µm film capacitors

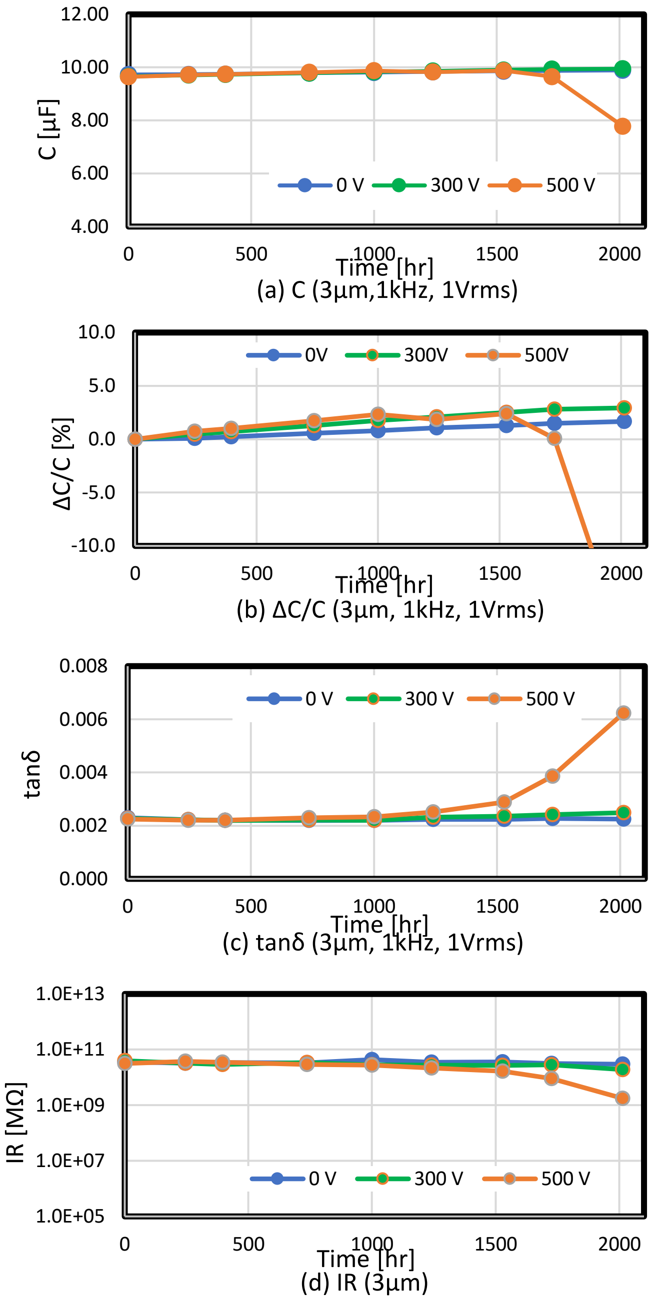


Fig. 7 Aging Test for 3µm film capacitors

