



Inside *iCoupler*® Technology: High Voltage Endurance

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As discussed in a previous Inside *iCoupler* Technology issue, the polyimide insulation used in *iCoupler* digital isolators provides high breakdown strength and ESD performance, thermal and mechanical stability, excellent chemical resistance, and low relative permittivity. This letter reviews the high voltage (HV) lifetime characteristics and how they differ from other insulation materials, such as SiO₂, that may also be used for high voltage insulation. Using demonstrated models and empirical data, the HV lifetime of *iCoupler* products is greater than 65 years at working voltages up to 400 V rms.

The dominant breakdown mechanism is through charge injections as a result of the direct electron impact from the electrodes to the polyimide surface regions. The breakdown process begins as charges are injected into polyimide surface under HV_{ac} conditions. The charges can become trapped in some local trapping sites at the surface. Once trapped, energy will be released, which will cause local mechanical tension because of stored electrostatic energy. Through quantum activation process, this tension will eventually cause local free volumes, voids, or micro-cracks, which act as more local trapping sites. If the HV_{ac} remains long enough, this process will lead to the continued degradation of insulation and eventually electrical punch-through.

Through thermodynamic analysis, the lifetime, *L*, can be expressed as

$$L \sim \frac{e^{-(E-E_t)^n}}{(E-E_t)^m} \quad [1]$$

where *E_t* is the threshold field where no charge injection will happen, and *m*, *n* are scaling constants.

The HV_{ac} endurance data of *iCoupler* devices was analyzed according to the procedure specified by ANSI/IEEE std 930-1987, the “IEEE Guide for the Statistical Analysis of Electrical Insulation Voltage Endurance Data”, and it is observed to follow

$$L \sim e^{V^{-n}} \quad [2]$$

This phenomenological fit was used to get worst-case lifetime because it assumes no threshold field as specified by the thermodynamic model. The duration of the HV test becomes prohibitively long if we try to measure the threshold field. As shown in Figure 1, Equation 2 (green curve) fits nicely with the data (black circles), and Equation 1 (red curve) tends to predict much longer lifetime at low voltages. The Arrhenius equation $L \sim e^{-V}$ (gray curve) followed by other dielectric material such as oxide clearly cannot fit our data.

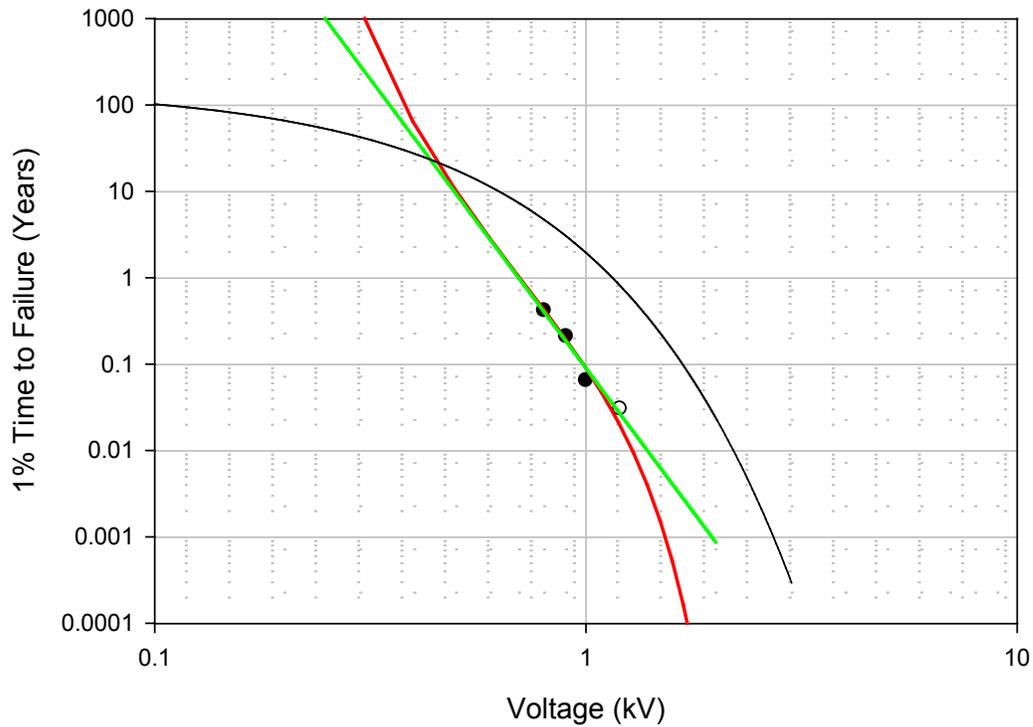


Figure 1: HV lifetime characteristic for *iCoupler* devices

We also observed that the lifetime of *iCoupler* devices under dc or unipolar ac is much longer compared to that under bipolar ac; it is at least two orders of magnitude higher. For unipolar waveforms, the trapped charges tend to form an internal field barrier region around the electrodes that prevents further injection of charge into the polyimide as shown in Figure 2. With a bipolar ac waveform, the reverse of field will prevent formation of this steady field barrier, and the trapped regions will keep progressing into the polyimide and eventually lead to the electrical breakdown. SiO₂, on the other hand, tends to give worse lifetime for dc or unipolar ac.

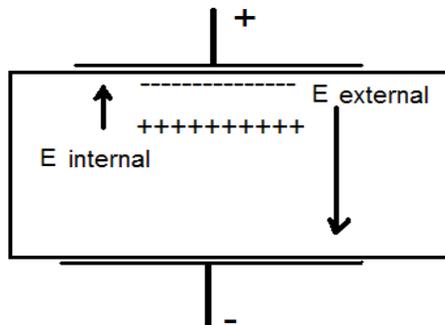


Figure 2: Field barrier region with zero net e-field formed by the trapped charges

ADI has performed extensive HV lifetime reliability testing and, using the models described above, has determined that the HV lifetime of *iCoupler* products is at least 65 years at working voltages up to 400 V rms. This lifetime is based on worst-case bipolar ac waveforms. HV lifetime is even greater for unipolar ac or dc waveforms. It should be noted that the models described in this letter relate to polyimide insulation and have no bearing on isolators that use SiO₂ insulators as the primary means for isolation. Likewise, models that predict the HV lifetime of SiO₂-based digital isolators have no bearing on polyimide-based isolation systems.

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References:

[1] L. A. Dissado, et al, "The incorporation of space charge degradation in the life model for electrical insulating materials", IEEE Trans. On Dielect and El. Ins., Vol. 2, No. 6, pp 1147-1158, December, 1995.