APPLICATION NOTE

ANO006 | Lifetime of Optocouplers

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01. INTRODUCTION AND THEORETICAL BACKGROUND

One of the main considerations in circuit design is the expected lifetime, based on the product itself and the single components included. When considering the components themselves, some can fail completely or degrade in performance with time. For optocouplers, the performance (Current – Transfer - Ratio) degrades over time depending on the operating conditions. This application note gives a quick introduction, how Würth Elektronik eiSos tests the lifetime of optocouplers, how you can calculate the expected lifetime for your application and it will give you tips on how to operate the optocouplers in order to increase the lifetime.

Today, optocouplers are widely used in power supply, home appliances, industrial control and other regulating and controlling applications. As isolation devices, optocouplers were invented in 1963 at IBM [1] and have come a long way from its origin as a simple light bulb coupled with a photo resistor. Maturing technology of solid state light sources i.e. the LED, have lead to a miniaturization of the optocoupler and its wide usage in industry as an isolation device. Today most typical optocouplers consist of an LED that is optically coupled to a phototransistor, photo-Darlington or photo-Triac. From the beginning, the lifetime of the LEDs was an issue, and even though the reliability of LEDs has steadily increased, it is still worth taking its' lifetime into account when considering optocouplers for applications.

The major root causes of failures in LEDs can be divided into die-bonding related failures and package-related failures [2]. Package related failures, which appear as early life failures, are a result of fabrication errors or miss-handling. Examples of those include wrong soldering profile, increased humidity during soldering or temperature induced stress on bonds, e.g. thermomechanical stress between bonding wires and transparent epoxy, which seals the LED [3]. Die related failures or degradation, which affect the lifetime of LEDs are related to thermal management during operation which is in direct relation to the nominal current of the diode and the heat dissipation. Thermal stress in the LEDs` junction zone results in lower light and thus has a direct impact on the component´s efficiency (CTR factor) [4].

This Appnote will focus on the long-term failure of optocouplers that is related to the decreasing light output of the LEDs with time, due to long-term operation and accompanying failure mechanism, in this case a form of the so-called electromigration.

02. OPTOCOUPLER

2.1 Basics

The simplest optocoupler consists of an LED optically coupled to a phototransistor but being electrically isolated from each other. The LED is turned on and off to emit light, which switches the phototransistor on, or off. An important parameter describing the optocouplers' performance is the Current – Transfer – Ratio (CTR). It is defined as the ratio of the current flowing through the LED, I_F and the current flowing through the phototransistor, I_C.

$$CTR = \frac{I_C}{I_F} \cdot 100\,\% \qquad (1)$$

In Würth Electronics' optocoupler portfolio, the customer has the possibility to choose ratios from 50% up to 600%, divided into different range of bins, depending on the customer's application.

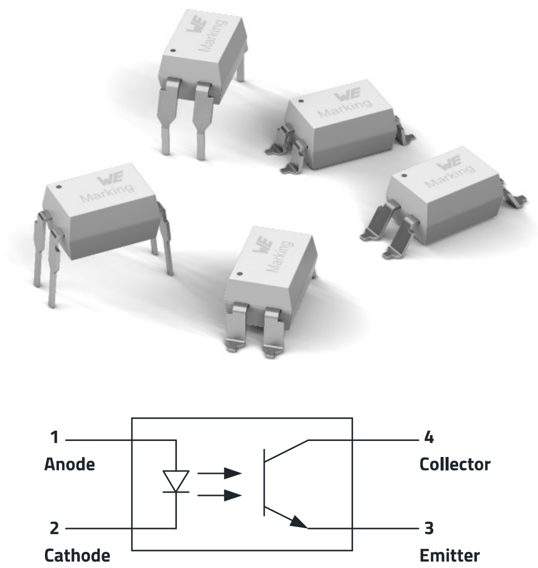

Figure 1: Würth Elektronik optocouplers using an LED and phototransistor for interaction between electrically separated circuits.

2.2 Introduction of lifetime testing

The lifetime of optocouplers can exceed several decades, therefore an accelerated stress test is performed, using increased operation conditions. In semiconductors, many different degradation mechanisms exist. Some of them are the electromigration [2], nucleation and growth of dislocations [3] and metal diffusion [2]. These degradation mechanisms can be described with specific activation energies E_A , which can be viewed as the energy required to activate this failure mechanism. Depending on the specific mechanism, this activation energy varies between E_A = 0.2 eV and E_A = 1.4 eV [4]. For LEDs, high current density and high temperature leads to diffusion of atoms out of the active region leaving point-defects [3]. These crystal defects increase the number of non-radiative recombination centers, thus decreasing the quantum efficiency of light creation and hence decreasing the CTR of the optocoupler. This mechanism can be described similar to the electromigration of Al atoms originally described by J. Black in 1969, where he described the median time to failure of a device with following formula [2].

$$\frac{1}{MTF} = A \cdot J^2 \cdot e^{-\frac{E_A}{k_B T}} \qquad (2)$$

MTF: Median time to failure [h]

A: A constant [5], including scattering cross section area

J: current density $\left[\frac{A}{cm^2}\right]$

E_A: Activation energy [eV]

k_B: Boltzmann constant $8.617 \cdot 10^{-5} \frac{eV}{K}$

T: Temperature [K]

For reliability testing it is of great interest to reduce the stress testing time but being able to predict the resulting lifetime under normal use conditions. According to equation (2), the MTF reduces with the current density and the temperature. When testing optocouplers with increased temperature and current, the degrading mechanisms happen much faster than they would under normal operation conditions with smaller temperature and lower current. Therefore, an acceleration factor can be calculated by dividing equation (2) with stress test conditions and normal operation conditions. This results in the widely known Black formula [2]:

$$AF = \left(\frac{I_{test}}{I_{norm}}\right)^N \cdot e^{\frac{E_A}{k_B}\left(\frac{1}{T_{norm}} - \frac{1}{T_{test}}\right)} \qquad (3)$$

AF: Acceleration factor median time to failure

T_{test}: Temperature used in stress test [K]

T_{norm}: Typical field use temperature [K]

I_{test}: Forward current used in stress test [A]

I_{norm}: Typical field use forward current [A]

E_A: Activation energy [eV]

N: Exponent [5] N=2

As mentioned above, there is a mixture of different failure mechanisms and corresponding activation energies. The effective activation energy can be found as a fit parameter from repeating stress tests at different temperatures. However, to comply with industry standards an average activation energy of E_A = 0.7 eV is used as a typical value for discrete semiconductors [4]. The application of this formula is demonstrated for the 14081614xxx/14081714xxx Würth Elektronik optocouplers, which were tested for 1000 h under increased temperature T_{test} = 110 °C and an LED forward current I_{test} = 30 mA. The phototransistor is less prone to degradation than the LED [6]. Therefore, for the scope of this application note, it is assumed that the change of CTR is due to the loss of luminosity of the LED and not due to phototransistor degradation.

In the following, an example of the acceleration factor calculation and its application to stress test results is shown. The test duration is 1000 h at T_{test} = 110 °C and a LED forward current I_{test} = 30 mA. If the optocoupler is used with 100% duty cycle at a forward current of I_{norm} = 5 mA and is operating at ambient temperature T_{norm} = 80 °C, the acceleration factor is AF = 218. So, according to the Black formula (3), the acceleration stress test of 1000 h simulates a normal field use of almost $A_F \cdot 1000$ h = 218 · 1000 h ≈ 25 years.

Figure 2 shows the CTR degradation that is expected within these 25 years. It shows for the Würth Elektronik optocouplers that in average, no more than 5% degradation of the CTR value is expected.

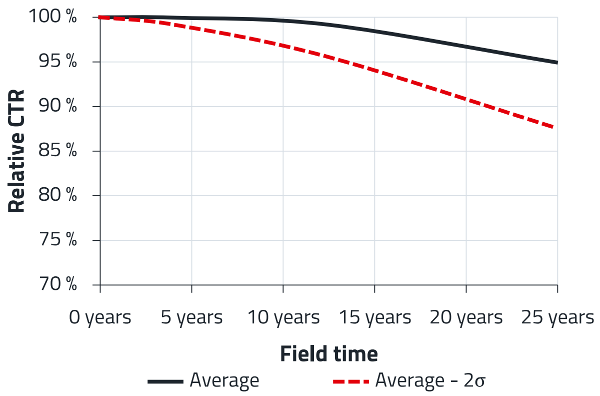

Figure 2: Expected CTR degradation with field time. Parameters for field use: 100% duty cycle, 80 °C ambient temperature, 5 mA forward current. Stress test parameters: 1000 h test, 110 °C test temperature, 30 mA forward current

The Average - 2σ relative CTRs are also given as a dashed line. Statistical distribution gives the variance 2σ as the amount of variation in the data. In other words – around 68% of the relative CTR values are inside of 1σ distance from the average value. Similar, 95% of the relative CTR values is within the 2σ confidence interval. When considering figure 2, the 2σ curve shows the lowest expected relative CTR degradation is not less than 87% within 25 years.

2.3 Parameters for improving optocoupler lifetime

In Figure 3 and Figure 4, the average CTR degradation is shown in dependence on the normal operation forward current I_F and the normal operation ambient temperature T. It is important to note that the expected CTR degradation can be reduced by reducing the operation temperature and driving forward current of the LED.

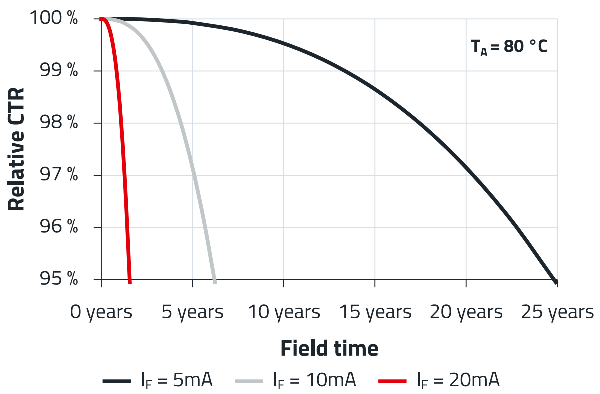

Figure 3: Forward current dependency on expected average CTR degradation with field time. Parameters for field use: 100% duty cycle, 80 °C ambient temperature, forward currents as indicated in the graph. Stress test parameters: 1000 h test, 110 °C test temperature, 30 mA forward current.

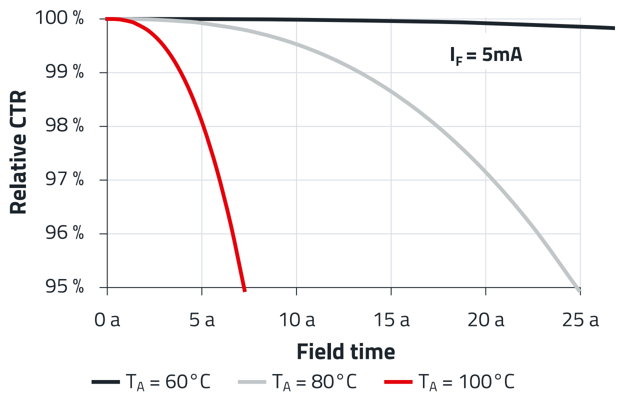

Figure 4: Temperature dependency on expected average CTR degradation with field time. Parameters for field use: 100% duty cycle, 5 mA forward current, ambient temperatures as indicated in the graph. Stress test parameters: 1000 h test, 110 °C test temperature, 30 mA forward current.

03. SUMMARY

Optocouplers, as all other components on the electronic board need reliable performance for many years in harsh applications such as industrial control and power supplies. As the reduction of the LEDs' performance is one of the mechanisms leading to a degradation of Current Transfer Ratio in optocouplers, it is worth describing and understanding this effect. Würth Elektronik eiSos performs extensive quality tests to provide products with outstanding reliability performance. Given the reliability data provided and the presented equations, we could suggest some design guidelines to increase the lifetime of optocouplers:

1. Decrease the effective operating time of the optocoupler.
2. Decrease the operating diode current and power dissipation out from the LED by larger vias and pads in the layout
3. Avoid peak transient currents through the LED
4. Adjust the duty cycle of the LED, in order to keep the average current low.

Additionally, in case of critical products regarding reliability like e.g. devices with medical application, reliability of the optocoupler can be increased by a burn-in procedure. But to avoid damage of the devices the burn-in parameters should be kept below the absolute maximum ratings. Keeping these rules in mind, the designer can expect a high stability of Würth Elektronik optocouplers performance for many years.

A Appendix

A.1 References

[1] I. Akmenkalns et al., "Four Terminal Electro-Optical Logic". United States of America Patent 3417249, 17 December 1963.

[2] J. Black, ""Electromigration - A Brief Survey and Some Recent Results"," IEEE Transactions on Electron Devices, 1969.

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[4] Component Technical Committee, "Failure Mechanism Based Stress Test Qualification for Discrete Semiconductors in Automotive Applications," Automotive Electronics Council, 2013.

[5] J. R. Black, "Mass transport of aluminum by momentum exchange with conducting electrons," IEEE International Reliability Physics Symposium, 1967.

[6] J. B. H. Slama, H. Helali, A. Lahyani, K. Louati, P. Venet and G. Rojat, "Optocouplers Ageing Process: Study and Modeling," in International Conference on Electrical Engineering Design & Technologies, Hammamet Tunisia, 2007.

[7] T. Bajenesco, "CTR degradation and ageing problem of optocouplers," in Proceedings of 4th International Conference on Solid-State and IC Technology, Bejing, China, 1995.Editors: E. Barsoukov, J. R. Macdonald, Impedance Spectroscopy: Theory, Experiment, and Applications, Third Edition, John Wiley & Sons (2018)

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