RELIABILITY OF OPTOELECTRONIC ELEMENTS. CIRCUIT SOLUTIONS FOR ITS IMPROVEMENT

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Reliability of optoelectronic elements (OEE) depends on a number of factors – temperature, vibrations, LED current. The failure mechanism of optoelectronic elements is determined by an exposure law as it is with other elements.

Keywords: Reliability, Optoelectronic Element, Frequency

1. FAILURE FREQUENCY

$$f(t) = \lambda.e^{-\lambda t}, h^{-1}, \qquad (1)$$

where: λ – failure intensity; t – operating time; h – hours.

Failure-free operation probability

$$P(t) = e^{-\lambda t}, \text{ dimensionless quantity} \qquad (2)$$

Lifetime

$$t = \frac{1}{\lambda}, h \qquad (3)$$

The total failure intensity, for example for one optocoupler, when failures take place independently

$$\lambda_{\Sigma} = \lambda_{LED} + \lambda_{ph} + \lambda_{c} \qquad (4)$$

where: λ_{LED} – intensity of LED failures;

λ_{ph} – intensity of photodetector failures;

λ_{c} – intensity of case failures.

The failure-free operation probability can be increased by using a structural excess (redundancy) – two parallel optocoupler channels.

$$P = 1 - (1 - P)^n \qquad (5)$$

When P=0.9 and n=2

$$P = 1 - (1 - 0.9)^n = 0.99$$

Failure classification in the different optoelectronic elements:

- LEDs and laser diodes – degradation and disconnected pins;
- photodetectors – high dark current, disconnected pins;

optocouplers – decrease of current transmission coefficient.

2. PULSE OPERATION MODE OF LEDS

Pulse LED dissipation is:

$$P_{FI} = U_{FI}.I_{FI} = 1.5.1 = 1.5W \qquad (6)$$

When I_{FI}=1A; U_{FI}=1.5V

The average dissipation is:

$$P_{Fmid} = \frac{t_I}{T} U_{FI}.I_{FI} = \frac{10}{1000}.1.5.1 = 15mW \qquad (7)$$

When T_I=10μs; T=1000μs; t_I/T=100

The temperature at which LEDs will be warmed up is:

$$t_{LED} = t_{en} + P_{Fmid}.R_{th} = 25 + 15.10^{-3}.500 = 32.5°C \qquad (8)$$

t_{en} – ambient temperature - 25ºC;

R_{th} – LED thermal resistance - 500ºC/W, at continuous radiation

$$P = U_F.I_F = 1.2.12.10^{-3} = 14.4mW \qquad (9)$$

When $U_F = 1.2V, I_F = 12.10^{-3}A$.

3. LED DEGRADATION

LEDs operate at high current density – up to 50 KA/cm^2. Degradation depends on LED current, operating time and temperature. Degradation leads to reducing LED radiation power – fig.1. Curve 1 indicates gradual degradation. Curve 2 consists of two parts, quick degradation up to 168 h. And slow degradation.

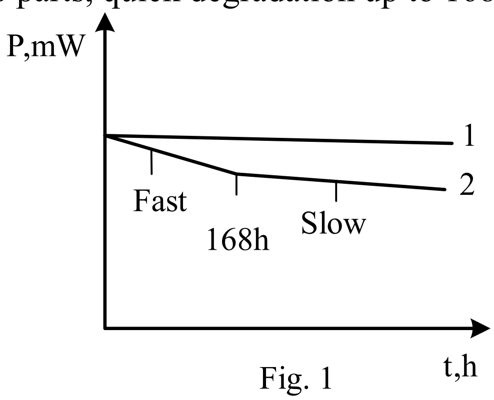


Fig. 1

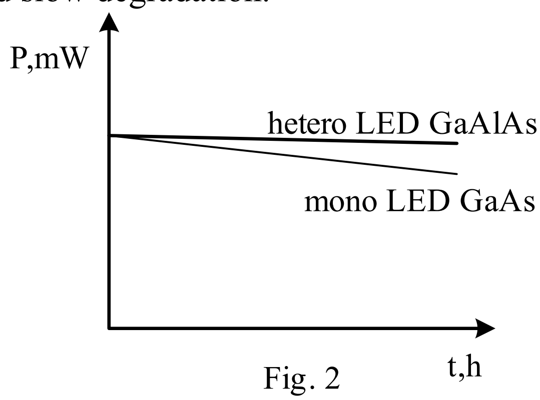


Fig. 2

Fig. 2 shows that with heteroLEDs the degradation is slower than with single-PN-junction LEDs.

Fig. 3 shows the LED VAX shift after operating 0 h.

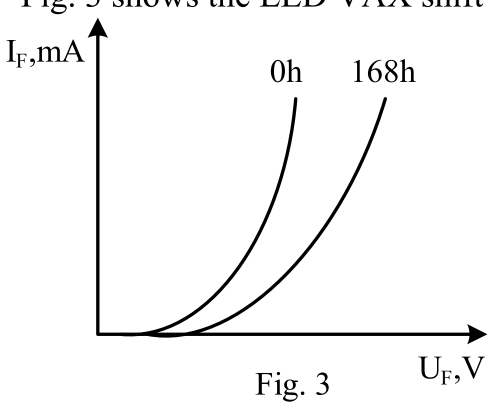


Fig. 3

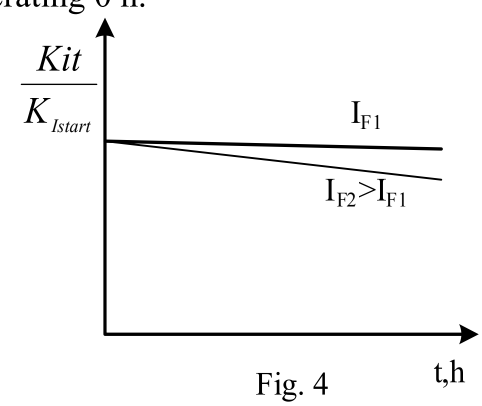


Fig. 4

LED degradation results in reducing the current transmission coefficient of optocouplers in the course of time – fig.4.

LED degradation is due to:

- manufacturing defects;
- influence of ambient factors (temperature, current).

For the time being there are only hypotheses describing degradation mechanisms. The hypotheses of Longini, Gold-Weisberg, etc. are well known. All hypotheses reduce the process to the appearance of defects in the centre of the forbidden band. Oggi's hypothesis explains degradation by increasing the non-radiation recombination. Arenius describes the LED medial resource (50%).

$$t_{50\%} = A.e^{\frac{Ea}{kT}} \quad (10)$$

A – constant

Ea – activity energy

K – Boltzmann's constant, k=8.63.10^{-5}eV/K

T – absolute temperature, ºK

General Electric Company proposes that degradation should be described according to three factors – time, temperature and LED current.

$$t_x = 10^{\left[\log\frac{t_0}{50}\cdot\frac{A_{T2}}{A_{T1}}.A_I + \log 50\right]} \quad (11)$$

t_x – operating time, h

t_0 – accelerated test time– 168h

A_{T1} – temperature accelerations under stress conditions

A_{T2} – temperature accelerations under working conditions

$\frac{A_{T1}}{A_{T2}}$ - coefficient depending on the slope of the curves' decade depending on temperature.

For example, at 100ºC up to 55ºC – 2.83/1.75=1.62

A_I – current relationship for LED current 100mA/10mA – 2.5

$$t_x = 10^{\left[\log\frac{168}{50}.(1.62).(2.5) + \log 50\right]} = 6770h$$

We are proposing the following solutions as regards circuit design, insensitive to LED degradation:

1. Operation of LEDs at low temperature
2. Cooling of LEDs
3. Operation with a low LED current and a low mark-to-space ratio.
4. Usage of optocouplers with a high CTR (K_i)
5. Output high-Ohm load
6. Usage of negative optical feedback
7. Operation with the LED current up to 50% of the catalogue value
8. Initial thermo-current training of LEDs and accelerated tests
9. Usage of heteroLEDs

4. CRITERIA FOR OPTOCOUPLER LIFETIME

- Photodetector dark current
- Current transmission coefficient K_I

The relative change of the current transmission coefficient is:

$$\frac{\Delta K_I}{\Delta K_{Istart}} = \frac{\Delta\eta}{\Delta\eta_{start}}\left[1+\left(1+\frac{\eta_{start}}{\Delta\eta}\right)\frac{\Delta B}{B_{start}}\right] \qquad (12)$$

където: η – LED efficiency;

η_{start} – initial LED efficiency;

$\frac{\Delta\eta}{\eta_{start}}$ - relative change of LED efficiency for a given time interval;

B – amplification factor of the output amplifier;

B_{start} – initial amplification factor of the output amplifier;

$\frac{\Delta B}{B_{start}}$ - relative change of the amplifier amplification by LED degradation leading to the decrease of the photodetector photocurrent.

$$\Delta B = B_{end}\left(I_{phend}\right) - B_{start}\left(I_{phstart}\right) \qquad (13)$$

$$K_I = \frac{I_{ph}}{I_F} \qquad (14)$$

I_F – LED current;

I_{ph} – photocurrent

Photodiode optocouplers are taken as an example:

Let I_F = 10mA and η goes down by 15 % to 10000h, that is $\Delta\eta/\eta=0.15$. From the photodiode transfer characteristic $I_{ph}=f(I_F)$. Let $I_{ph0}=20\mu A$ and $B_0(I_{ph0})=100$

$$I_{phend} = \frac{I_{phstart}}{1+\frac{\Delta\eta}{\eta}} = \frac{20.10^{-6}}{1+0.15} = 17.39\mu A \qquad (15)$$

Let $B_{end} = 99$

$$\Delta B = B_{start} - B_{end} = 100 - 99 = 1$$

$\frac{\Delta B}{B} = \frac{1}{100} = 0.01$ then from (12)

$$\frac{\Delta K_I}{K_I} = 0.15\left[1+\left(1+\frac{1}{0.15}\right).\frac{1}{100}\right] = 0.16$$

5. CIRCUIT SOLUTIONS FOR REDUCING DEGRADATION

Compensation in the LED circuit – fig. 5

Compensation in the phototransistor circuit – fig. 6

Circuit with double compensation – in the LED circuit and in the phototransistor circuit – fig.7.

6. CONCLUSIONS

Analytical and graphic factors influencing the reliability of the optoelectronic elements have been described. Solutions and circuits for reducing the influence of degradation on optoelectronic elements have been proposed.

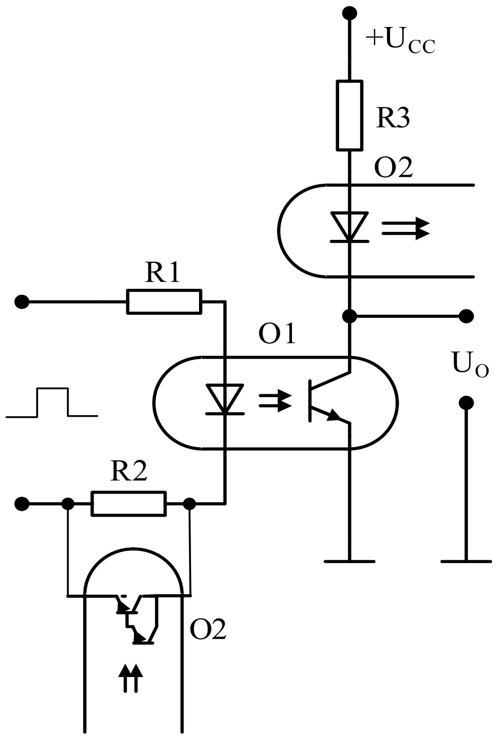


Fig. 5

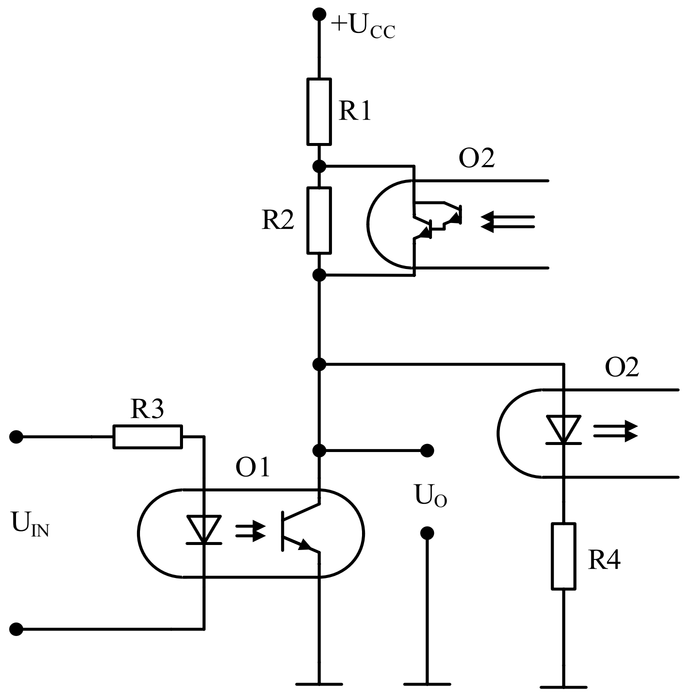
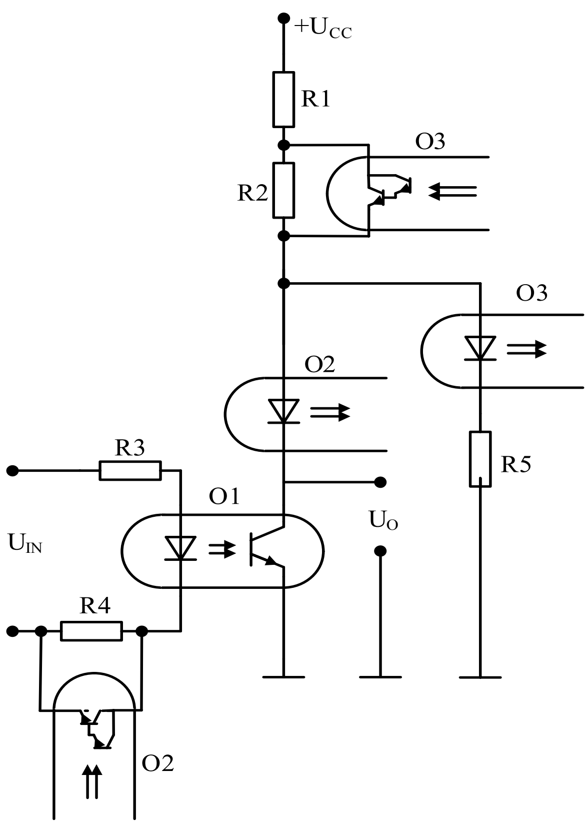


Fig. 6



Фиг. 7

7. References

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