JOURNAL OF OPTOELECTRONICS AND ADVANCED MATERIALS Vol. 9, No. 12, December 2007, p. 3881 - 3884

Influence of working conditions on over-voltage diode operation

M. VUJISIĆ*, P. OSMOKROVIĆ, K. STANKOVIĆ, B. LONČAR[a]
Faculty of Electrical Engineering, University of Belgrade,Bulevar Kralja Aleksandra 73, 11120 Belgrade, Serbia
[a] *Faculty of Technology and Metallurgy, University of Belgrade, Karnegijeva 4, 11120 Belgrade, Serbia*

This paper investigates the influence of temperature variation, aging and radiation exposure on over-voltage diode operation. Behaviour of over-voltage diodes in the temperature range from –50ºC to +150ºC is examined. Aging is investigated by applying 1000 consecutive double exponential over-voltage pulses to the diode. Radiation effects of a combined neutron/gamma radiation field are analyzed. Volt-ampere characteristic, volt-ohm characteristic, and the value of breakdown voltage are used to characterize over-voltage diode operation, along with the nonlinear coefficient defined from the volt-ampere curve. Over-voltage diodes showed severe impairment of protective characteristics after being exposed to radiation or increased temperature, while on the other hand they proved to be highly resistive to aging. Theoretical interpretation of the observed changes in over-voltage diode behaviour is also provided in the paper.

(Received May 28, 2007; accepted December 4, 2007)

Keywords: Over-voltage diodes, Aging, Radiation effects, Temperature

1. Introduction

Over-voltage conditions are rather common phenomena in all electronic circuits, which makes efficient over-voltage protection a primary design requirement. An efficient over-voltage protection has two aspects: protection of integrity (no permanent damage of the protected device) and maintainance of operational functionality (operation reliability in the event of an over-voltage). Both power systems (energy generation, transmission and distribution) and low-voltage (electronic) systems, are susceptible to over-voltages. The extent to which an electronic component can withstand a temporary over-voltage without damage is reduced significantly as components are miniaturized. An over-voltage may be a consequence of energy redirection within a power system (switching over-voltages), or it could be an outcome of electrostatic discharge (including lightning). In an extreme case, a nuclear explosion may also bring about an over-voltage [1,2].

Over-voltage protection components can generally be divided into nonlinear and linear ones. The nonlinear group includes over-voltage diodes (also called transient voltage suppressor diodes), metal-oxide varistors, and gas-filled surge arresters. The linear group of over-voltage protection components includes capacitors, inductors, resistors, or their combinations as filters. In practice, various hybrid schemes combining the linear and non-linear components are often used.

The main disadvantage of linear over-voltage protection components is the frequency dependent efficiency of protection. For all nonlinear protective devices this is only a marginal problem, and only at very high frequencies may the protection efficiency of these devices suffer certain degradation. Reliable operation of over-voltage diodes at high temperatures is extremely important, particularly in "mission critical" applications. Stable operation of over-voltage diodes in a wide temperature range significantly contributes to overall system reliability. Protective characteristics of over-voltage diodes are also dependent on past exploitation, i.e. on the aging process. Aging is an irreversible destructive process caused by component's normal operation. Effects of aging are a consequence of construction and material imperfections, which critically influence the performance and reduce the service-life of an over-voltage component. The necessity of using modern electronic devices in radiation conditions, e.g. in military industry and space technology, raises the question of over-voltage diode reliability under exposure to ionizing radiation [3]. The aim of this paper is to investigate the influence of temperature variation, aging and radiation exposure on over-voltage diode characteristics [4, 5].

2. The experiment

Commercially avaliable over-voltage diodes, with 250 V nominal voltage, were used for the experiments. Diodes were all produced by a single manufacturer, with identical nominal characteristics, which resulted in low statistical dispersion of the obtained resilts. Each series of measurements has been performed on a sample consisting of 50 diodes. Diode characteristics presented in the paper are based on sample mean values.

Measuring equipment consisted of a current source (with a 3000 V maximum voltage), a digital oscilloscope, a dc high-voltage power supply and a personal computer. All measuring instruments were protected from electromagnetic interference by electromagnetic shielding. The experimental procedure was fully automated. This approach assured very high accuracy of measurement and good repeatability of results. Specialized PC-based control software (HP-IB or IEEE488 protocol) was developed to provide overall experiment sequencing, measurement and data acquisition.

The influence of diferent exploitation conditions on over-voltage diode operation was investigated by monitoring some or all of the following: a) volt-ampere characteristic, b) volt-ohm characteristic, c) breakdown voltage, and d) the nonlinear coefficient α, defined as:

$$\alpha = \frac{\log \frac{I_2}{I_1}}{\log \frac{U_2}{U_1}} \tag{1}$$

where (U_1, I_1) and (U_2, I_2) are points taken from the volt-ampere curve. Experiments consisted in applying double exponential current pulses (13 A, 8 × 20 μs) to the diodes and recording voltage response at the falling edge of the current pulse, while varying the exploitation conditions. Prior to each series of measurements, over-voltage diodes were conditioned with 25 breakdowns. A thirty-second pause between two successive measurements was introduced. The volt-ohm characteristic was calculated from the volt-ampere curve.

Temperature dependent investigations were performed in the temperature range from –50ºC to +150ºC. The influence of aging was investigated after 1000 activations by the double exponential current pulse. Radiation related changes of diodes' characteristics were investigated by exposing the diodes to a combined neutron/gamma radiation field of the Californium-252 source. Californium ^{252}Cf isotope, encapsulated in the form of Cf_2O_3, was used. The mass of the used ^{252}Cf radionuclide was 2.265 μg, its specific neutron and gamma emission rates $2.34 \cdot 10^6$ (μg s)$^{-1}$ and $5.3 \cdot 10^9$ (μg s)$^{-1}$, respectively. Average neutron energy of the ^{252}Cf source is 2.14 MeV, and average gamma photon energy is 0.88 MeV. Diodes were exposed to three different levels of total neutron and gamma fluences (Φ_n and Φ_γ respectively), given in Table 1 in ascending order. Each fluence level is marked by a number (n_Φ) shown in the first column.

Table 1. Values of Neutron (Φ_n) and Gamma (Φ_γ) Fluences Used for Irradiation.

n_Φ	Φ_n [10^{10} cm^{-2}]	Φ_γ [10^{13} cm^{-2}]
1	3.55	8.66
2	7.10	17.3
3	10.66	26

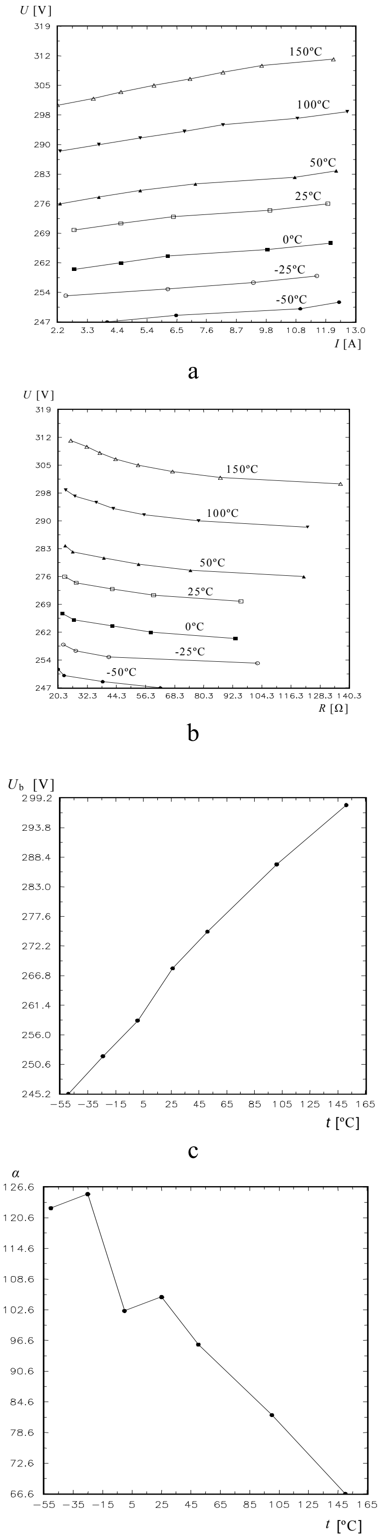
3. Results and discussion

Fig. 1(a)-(d) shows the influence of temperature on volt-ampere characteristic, volt-ohm characteristic, breakdown voltage, and the nonlinearity coefficient of an over-voltage diode. The over-voltage diode exhibits a decrease of breakdown voltage with the rise of temperature (due to an avalanche mechanism). Increase of the volt-ampere characteristic slope has been also detected (consequently, the nonlinear coefficient α decreases - due to the increase of diode's specific resistance). Theoretical explanation of this phenomenon can be found in the somewhat decreased mobility of carriers in the breakdown region. This is a consequence of the diode inverse current increase. As expected, over-voltage diodes have rather reliable characteristics in the temperature range from –50ºC to +90ºC. Application of an over-voltage diode is not recommended for temperatures beyond +90ºC, since significant degradation of its protective characteristics occurs at higher temperatures [6-8].

Fig. 2 shows the over-voltage diode volt-ampere characteristic as it depends on the number of activations. After completing the test (1000 activations) an increase in dynamic resistance is noticeable, and volt-ampere characteristic becomes concave at large currents. This can be explained by irreversible changes of fundamental parameters of transport processes in the p-n junction (metalization, subsequent diffusion, tunneling, minority carrier injection, appearance of oxidation layers, edge effects) due to heating and annealing on the contacts.

Consequences of the aging process are the changes in the main parts of an over-voltage diode (p-n junction, protection layers and contact system) and on their interfaces. Modifications of the p-n junction are caused by the emersion of various defects in the structure (point defects, local mechanical strain etc.). Aging of contacts results from the effects of metallization, i.e. diffusion of metal atoms into the semiconductor, where the impurity composition is changed [9,10].

Fig. 3(a)-(d) shows the volt-ampere characteristic, volt-ohm characteristic, breakdown voltage, and the nonlinearity coefficient of an over-voltage diode with the fluence level number n_Φ as a parameter. According to these diagrams, over-voltage diodes exhibit breakdown voltage drop, due to the increase of the volt-ampere slope, and consequently the decrease of the non-linear coefficient. The changes which were noticed could be explained by irreversible material changes caused by neutron/gamma radiation.



a

b

c

d

Fig. 1. (a) Volt-ampere characteristic, (b) Volt-ohm characteristic, (c) Breakdown voltage, (d) Nonlinearity coefficient of an over-voltage diode at different temperatures in the (–50°C, +150°C) range.

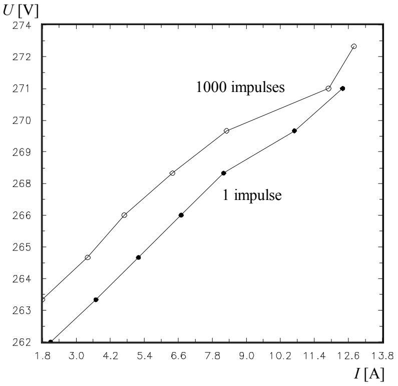
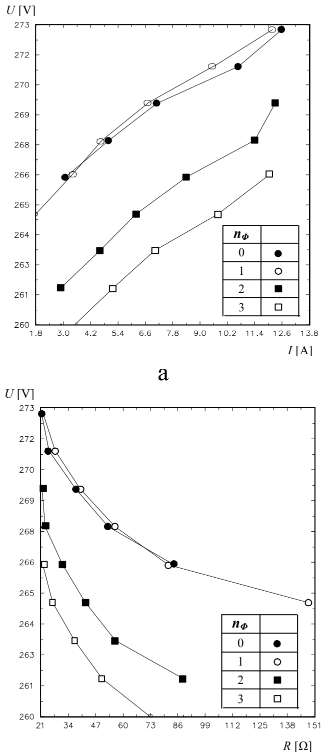


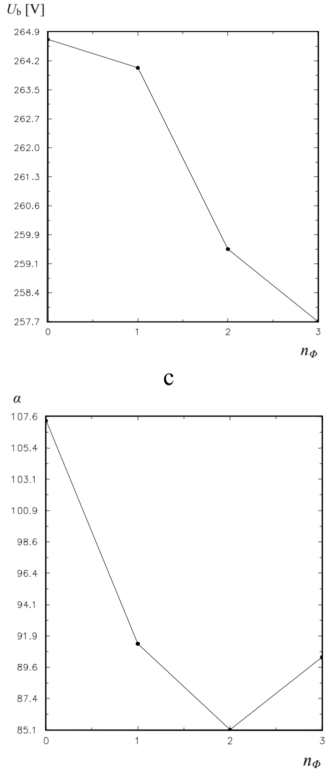
Fig. 2. Over-voltage diode volt-ampere characteristics as it depends on the number of activations.

Various radiation induced defects cause direct degradation of over-voltage diode characteristics, such as minority charge carrier concentration and mobility, specific resistance etc. The most common radiation defect for doses applied in ths paper is the Frenkel pair, consisting of a displaced interstitial atom and a vacancy. Energy levels of these defects, as well as of the stable complexes which they form with atoms of impurities and dopants present in the semiconductor, are located inside the energy gap.



a

b



c

d

Fig. 3. (a) Volt-ampere characteristic, (b) Volt-ohm characteristic, (c) Breakdown voltage, (d) Nonlinearity coefficient of an over - voltage diode with the fluence level number n_Φ as a parameter.

Some of these defects represent very efficient recombination centers. Recombination probability of minority carriers depends on the concentration of recombination centers. Minority carrier recombination rate becomes higher in an irradiated semiconductor material, which consequently decreases minority carrier lifetime. This causes diode inverse current to become larger, leading to the breakdown voltage decrease. Another radiation effect is the decrease of minority carrier mobility and concentration, which causes the increase of the semiconductor material specific resistance. Consequently, the nonlinear coefficient decreases and the over-voltage diode protection characteristics degrade. The influence of the neutron component of radiation field on diode degradation is much larger than the influence of the gamma component, since at energies characteristic of the Californium-252 source neutrons cause significantly more displacements of atoms from the crystal lattice [11-20].

4. Conclusion

Experimental results have shown over-voltage diodes to be sensitive to temperature variation. At temperatures higher than +90ºC protective characteristics of over-voltage diodes are considerably degraded. It has also been observed that combined neutron/gamma radiation exerts a significant detrimental influence on over-voltage diode operation. On the other hand, over-voltage diodes proved to be highly resistive to aging.

Acknowledgment

The Ministry of Science and Environmental Protection of the Republic of Serbia supported this work under contract 141046.

References

[1] J. Foster, "Break-over Diodes for Transient Suppression", Electronic Engineering (1987).
[2] M. Beyer, W. Boeck, "Hochspannungtechnik, Theoretische und praktische grundlagen", Springer-Verlag, Berlin (1986).
[3] B. Loncar, P. Osmokrovic, S. Stankovic, R. Sasic, J. Optoelectron. Adv. Mater. **8**(2), 863 (2006).
[4] C. Howard, "New Avalanche Diode For Transient Protection", Electronic product design (1983).
[5] C. Gjaerde, IEEE Trans. Dielectr. Electr. Insul. **4** 674 (1997).
[6] B. Lončar, P. Osmokrović, S. Stanković, IEEE Trans. Plasma Sci. **30** 1881 (2002).
[7] E. Barberis, J. G. Boissevain, N. Cartiglia, J. A. Ellison, P. Ferguson, J. K. Fleming, K. Holzscheiter, S. Jerger, D. Joyce, J. S. Kapustinsky, J. Leslie, C. Lietzke, J. A. J. Matthews, A. P. T. Palounek, D. Pitzl, W. A. Rowe, H. F. -W. Sadrozinski, D. Skinner, W. F. Sommer, W. E. Sondheim, S. J. Wimpenny, H. J. Ziock, Nucl. Inst. and Meth. A **326** 373 (1993).
[8] N. W. Ashcroft, N. D. Mermin, "Solid State Physics", Holt, Rinehart & Winston, New York (1976).
[9] P. Osmokrović, B. Lončar, S. Stanković, A. Vasić, Microel. Reliability **42** 1959 (2002).
[10] V. S. Vavilov, N. A. Ukhin, "Radiation Effects in Semiconductors and Semiconductor Devices", Consultants Bureau, New York (1977).
[11] G. Holmes-Siedle, L. Adams, "Handbook Of Radiation Effects", Oxford University Press (2002).
[12] G. C. Messenger, M. S. Ash, "The Effects of Radiation on Electronic Systems", Van Nostrand Reinhold, New York (1992).
[13] P. Osmokrović, M. Stojanović, B. Lončar, N. Kartalović, I. Krivokapić, Nucl. Inst. and Meth. In Physics Research B **140** 143 (1998).
[14] R. Alexander, IEEE Trans. Nucl. Sci. **50** 565 (2003).
[15] A.Vasić, P. Osmokrović, B. Lončar, S. Stanković, Materials Science Forum **494** 83 (2005).
[16] E. Normand, "Radiation Effects In Commercial Electronics", IEEE Nuclear and Space Radiation Effects Conference Short Course (1994).
[17] Lončar, P. Osmokrović, M. Stojanović, S. Stanković, Japanese Journal of Applied Physics, **40** 1126 (2001).
[18] S. Stanković, R. Ilić, P. Osmokrović, B. Lončar, A. Vasić, IEEE Trans. Plasma Sci. **34** 1715 (2006).
[19] J. V. Milanovic, C. P. N. Fu, R. Radosavljevic, Z. Lazarevic, Electric Power Components and Systems **29** 867 (2001).
[20] A.Vasić, S. Stanković, B. Lončar, Materials Science Forum **413** 171 (2003).

---

[*] Corresponding author: vujsa@ikomline.net