Tr. J. of Physics
23 (1999) , 485 – 491.

Ionizing Radiations and Annealing Influence on MOSFET Charge States.

Zainabidinov CİRAGİDDİN, Atamuratov ATABEK, Ysupov AKHMED, Adinaev KUVONDİK
Physics Department, Urgench State University, Republic Uzbekistan.
740000 Urgench City, H. Olimjan street, 14.

Received 13.02.1997

Abstract

The threshold voltage shift ΔV_T and its components due to trapped-oxide charges ΔV_{Not} and $Si-SiO_2$ interface traps ΔV_N in MOSFET exposed to Bremsstrahlung, Co_{60} irradiation and annealing were studied. Several effects caused by differences in the photon energies from two types of sources are discussed as well as a mechanism of changing the trapped-oxide and $Si-SiO_2$ interface traps by annealing. The mechanism is based on previously available models.

Introduction

New defects appear in oxide and $Si-SiO_2$ interface under external influence. Those defects are connected with some states and charges on them. But there is still no good understanding of what causes which changes in MOSFET charge states. Mechanisms of some charge states appearing then being annihilated are discussed.

It is important to note that the results of different experiments often do not confirm and sometimes even exclude each other. Therefore it is interesting to investigate MOS transistor parameters changes due to different affects. This paper is an experimental study of both MOS transistors threshold voltage shifts and its components due to both trapped-oxide charge and $Si-SiO_2$ interface trap shifts caused by bremsstrahlung, Co_{60} irradiation and annealing.

Experimental Proceure

In this experiment we have used p-channel MOSFETs. Samples with gate oxide thickness 0,2 μm were grown in dry oxygen at $1150°C$. Dry oxygen contained a little (3%) hydrogen chloride in gaseous condition.

Photons from both bremsstrahlung having maximum energy 30 MeV and Co_{60} irradiation source were used. Energy fluence density at the sample location was 0.195 W/cm^2 for bremsstrahlung and 0,120 W/cm^2 for Co_{60} radiation. Sample were irradiated in the 1-10^4 J/cm^2 range. All pins of the transistors were grounded for each exposure. The results were shown as functions of radiation energy transfer F (J/cm^2) at location of exposure. The radiation energy transfer was determined from radiation energy fluens density I (W/cm^2) by.

$$F = I \star \Delta t,$$

where Δt is exposure time (sec). The bremsstrahlung energy density was controlled by a standard IK-MsV ionizing chamber in the sample location place. The IK-MsV is a thin-wall passable flat ionizing chamber. The device was calibrated by a P2-2M thick-wall ionizing chamber. The radiation energy fluence density of the Co_{60} source was determined by an exposure dose from a standard DOG-25/200 dosimeter.

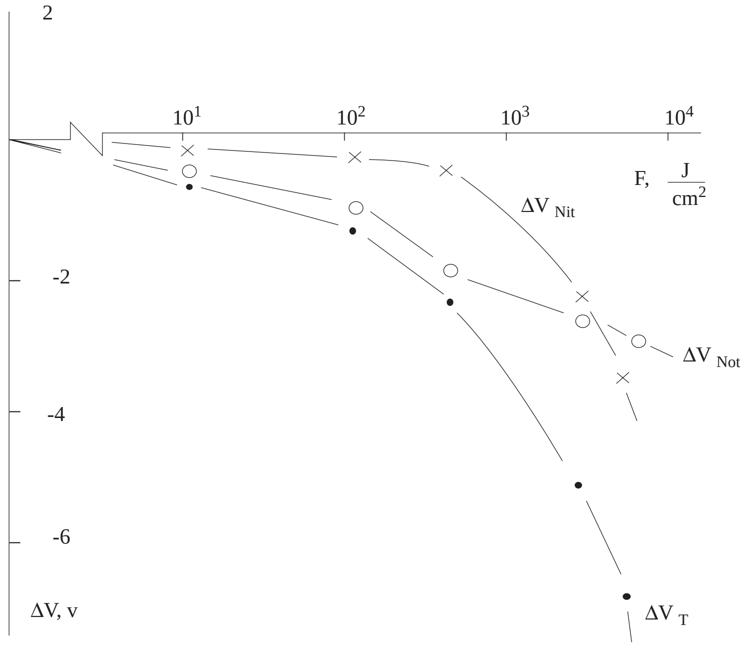

Figure 1. ΔV_T, ΔV_{Nit} and ΔV_{Not} as functions of bremsstrahlung energy transfer in the sample location plase.

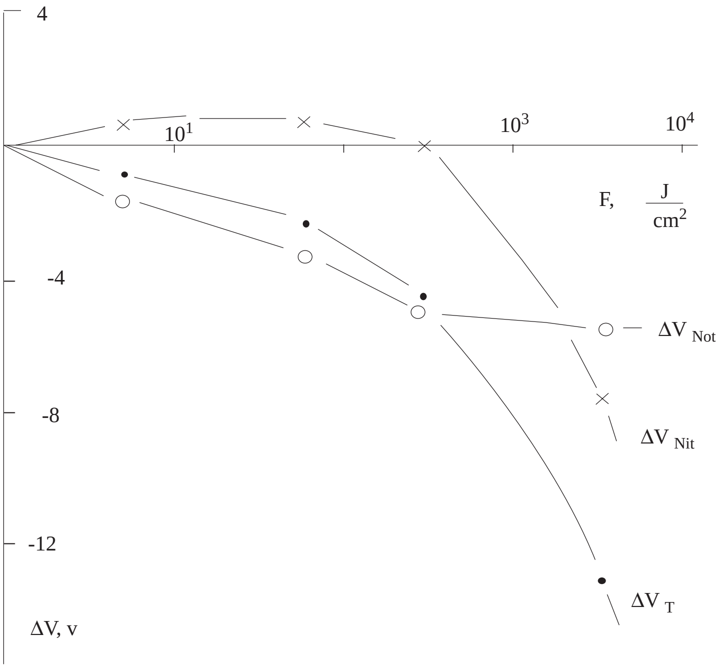

Figure 2. ΔV_T, ΔV_{Nit} and ΔV_{Not} as functions of Co-60 energy transfer in the sample location plase.

Experimental Results

Standard subthreshold measurements [1] were performed to obtain the component of the transistor threshold voltage shift that was due to interface-state charge (ΔV_{Nit}). The threshold voltage shift component due to oxide-trapped charge (ΔV_{Not}) was normally calculated by subtracting the shift due to interface states from the total threshold voltage shift [2]. In Fig.1 and Fig.2 we show ΔV_T, (ΔV_{Nit}) and (ΔV_{Not}) as functions of both bremsstrahlung and Co_{60} radiation energy transfer, respectively. In both cases the character of the ΔV_T (F) dependence is identical and monotonic. But rates of those dependences are not equal in the whole range of F values considered. In both cases the ΔV_{Not} changes are also monotonie and tending to saturation. However, the behaviour of ΔV_{Nit} does have small differences in the cases considered. Bremsstrahlung with F$<$ $5 \star 10^2$ J/cm^2 causes slow increase of ΔV_{Nit}. But if F$>$ $5 \star 10^2$ J/cm^2 then ΔV_{Nit} increase faster than ΔV_{Not}. Co_{60} radiation causes ΔV_{Nit} approach to small positive values when F$>$ $5 \star 10^2$ J/cm^2 and exhibits steep decreases to large negative values for F$<$ $5 \star 10^2$ J/cm^2. The MOSFETs irradiated by bremsstrahlung were heated over a wide range of temperatures (50° to 400°C). In Fig.3 ΔV_T, ΔV_{Nit} and ΔV_{Not} are shown as functions of the annealing temperature. ΔV_T practically does not change after heating at temperatures less than 210°C. But ΔV_{Nit} and ΔV_{Not} start to change significantly at 120°C.

However, ΔV_{Nit} approaches to larger negative values reaching their maximum at 210°C. At the same time ΔV_{Not} approach to small negative values and at greater temperatures occur small relaxation of the ΔV_{Not} (T) dependence. At this point the ΔV_T behaviour is being completely determined by the ΔV_{Nit} behaviour.

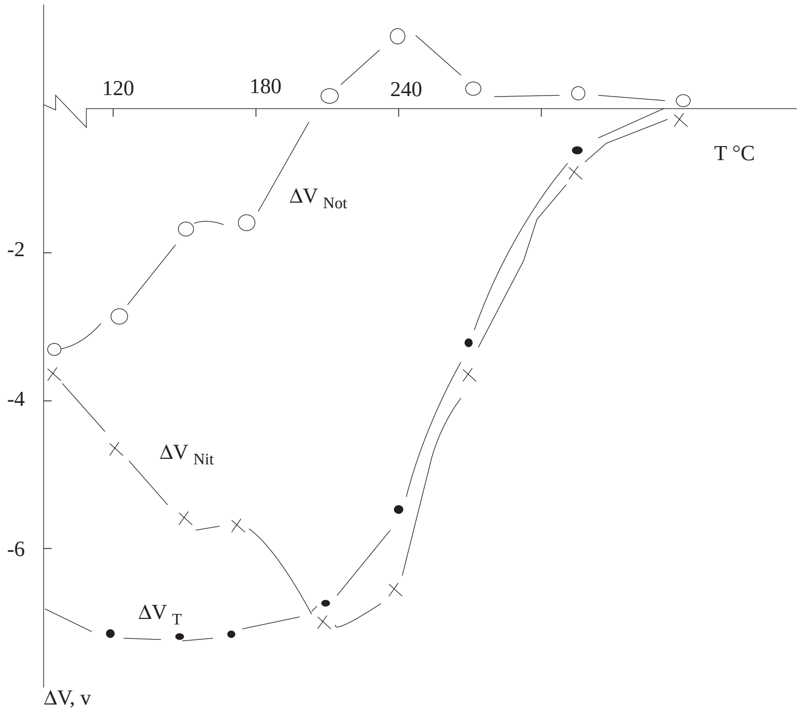

Figure 3. ΔV_T, ΔV_{Nit} and ΔV_{Not} as functions of the annealing temperature.

Discussions

All pins of the transistors were grounded for each exposure. The preirradiation field of about $0.2{\star}10^5$ v/cm across the gate oxide was due to work function differences between the gate and substrate (as well as other localized fields, such as those produced by trapped charges or impurities, if taken into consideration). For these values of oxide fields the fraction of electrons and holes escaping recombination depends on radiation photon energy [3]. It is proposed that high energy bremsstrahlung used by us has a photon energy distribution like the Shiff spectrum [4] (Fig. 4). It is known [4] that photons with energies from 0.01 to 0.4 MeV (their fraction is 4% of all the photon spectrum) have a photoeffect cross-section from $1.6{\star}10^{-21}$ to $2.02\ {\star}10^{-26}cm^2$/atom. The Compton effect cross-section for the same photons (that can also cause ionizing of a substance) has values from $8.96\star10^{-24}$ to $4.43\star10^{-24}cm^2$/atom. Photons with energies from 0.4 to 2 Mev (18% of all the spectrum photons) have a photoeffect cross-section practically equal to zero. Values for the Compton effect cross-section for those photons has range of 4.43 $\star10^{-24}$-$2.05\star10^{-24}cm^2$/atom, and is almost the same for CO_{60} source photons. The balance of the bremsstrahlung photons (78%) with energies from 2 to 30 Mev have a photoeffect cross-section practically equal to zero and a Compton effect cross-section from $2.05\star10^{-24}cm^2$/atom to $0.3\star10^{-24}cm^2$/atom. This means that the Compton effect cross-section for the main fraction of the bremsstrahlung photons is several times smaller then for CO_{60} source photons. And a small fraction of bremsstrahlung photons has a photoeffect cross-section not equal to zero, in distinction from CO_{60} source photons having photoeffect cross-section equal to zero. Therefore apparently it means that the electrons and holes quantity induced in oxide by bremsstrahling is less than CO_{60} radiation. As well as the fraction of electrons and holes escaped recombination by bremsstrahlung is less than by CO_{60} radiation. Evidently those reasons cause less ΔV_{Not} change by CO_{60} radiation than by bremsstrahlung although radiation energy transfers are equal. The ΔV_{Nit} (F) dependence grows slowly under the bremsstrahlung influence with small F values and grows fast when F values are high. The same function shifts to positive values under the influence of CO_{60} radiation with small F and grows fast when F is large (Fig.1). The behaviour of those dependences can be explained by competing influences of two mechanisms responsible for Si-SiO_2 interface state density change [5]. One of them is the creation of atomic hydrogen, which furthers the interface states annihilation more than generation. The other one is the reaction of interface states generation with participation of positive charged inclusions created by radiation (for instance H^+ [5] and/or holes [6]). Therefore, the interface state density decreases under the influence of CO_{60} photons with small F values (i.e. small dose), which probably can be explained by the creation of fewer positive charged inclusions and holes than of atomic hydrogen. But when energy transfers of bremsstrahlung are small (i.e., the doses are less than for CO_{60} radiation at the same F) and the interface states density decrease is not observed. This is obviously due to the inclusion of radiation induced positive chargs, and quantity of holes depends both on radiation dose and on radiation photons energy (according to ionizing capability) as well.

The reaction of appeazance of positive charged inclusions apparently predominates over the reaction of atomic hydrogen creation when radiation energy transfers are higher than $5\star10^2$ J/cm^2. Therfore, the generation of Si-SiO_2 interface states and high quantity of positive charged accumulation in oxide occurs. The accumulation of that charge is caused both by positive charge inclusions and trapped holes. The charge furthers the positive charged inclusions and holes drift to Si-SiO_2. The positive charged inclusions and holes participate in interface state generation reaction. Finally, a balance between processes of accumulation in oxide and of positive charged inclusios and holes drift to Si-SiO_2 interface is reached. As a result ΔV_{Nit} grows fast and ΔV_{Not} reaches saturation for $F>5\star10^2$ J/cm^2.

Upon heating over the temperature range from T=120°C to T=210°C ΔV_{Nit} (T) and ΔV_{Not} (T) dependencies testify to the increase of Si-SiO_2 interface state density and the decrease of oxide positive charge, respectively. This is apparently caused by drift of positive charged formations from the oxide to the Si-SiO$_2$ interface. On the Si-SiO$_2$ interface the positive charged formation participate in reactions which cause generation of the interface state. The ΔV_{Not} (T) dependence indicates that radiation induced positive charge and oxide states are practically completely annealed at T=210° C; and relaxation of the ΔV_{Not} (T) dependence at greater temperatures was obviously caused by relaxation of the positive charge in the oxide, a process which is genetically connected with the formation of the MOS structure. At temperatures higher than 210°C the ΔV_T behaviour mostly depends on fast states charge in the Si-SiO$_2$ interface. Those fast states are completely annealed at T=360°C. According to [7], decreased Si-SiO$_2$ interface states density may be caused by saturation of broken Si bonds at the Si-SiO$_2$ interface with CI ions. The CI ions become unbound from Si-SiO$_2$ at higher temperatures.

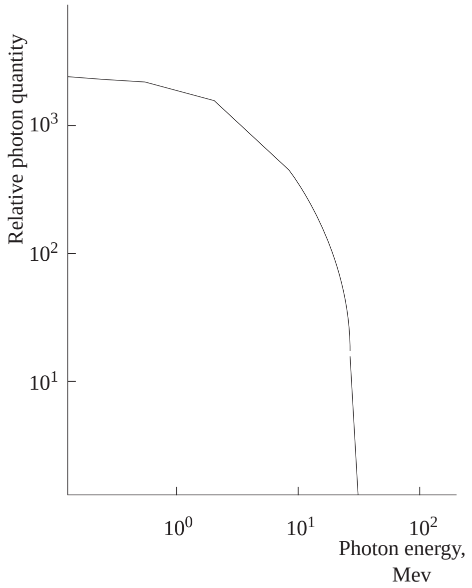

Figure 4. Photon energy distribution of high energy bremsstahlung used in this work.

The Conclusion

The results allow the following conclusions:

a) ΔV_{Not} shifts less under bremsstrahlung irradiation than from Co$_{60}$ photons irradiation, though the radiation energy transfers were the same in both cases. This phenomenon is apparently connected with the difference in quantities of radiation induced electrons and holes in the oxide and with the fraction escaping recombination;

b) The behaviour of ΔV_{Nit} is different for bremsstrahlung and Co$_{60}$ photons radiation. The cause is obviously due to that the radiation-induced positive charges and quantity of holes depends both on radiation dose and radiation photon energy.

c) The monotonic increase of ΔV_{Nit} and decrease of ΔV_{Not} upon heating to 210° C is apperently connected with presence positive charges and hole drift to the Si-SiO$_2$ interface, where they participate in interface states generation. The ΔV_{Nit} decrease at temperatures higher than 210° C is caused by interface states annihilation with hydrogen atoms which may or may not include CI ion participation. ΔV_{Not} relaxation at temperatures higher than 210° C is caused by relaxation of the positive charge in the oxide which is genetically connected with MOS structure formation.

Aknowledgements

The authors thank A. Uzbekov for technical help.

References

[1] P.J. Mcwhorter, P. S. Winokur, App. Phyz. Lett., Vol. 48, No 2 (1986), 133

[2] J. R. Schwank, P. S. Winokur, P. J. Mcwhorter, F. W. Sexton. P. V. Dressendorfer and D. C. Turpin.IEEE Trans. Nuc. Sci, Vol. NS-31, No 6. (1984), 1434

[3] C. M. Dozier and D. B. Brown, IEEE Trans. Nuc. Sci. NS-27 (1980) 1964.

[4] S. B. Starodubcev, A. M. Romaonov. Vzaimodeistvie gamma-izluchenie s veshestvom.CH.1, CH.2 (“Fan”, Tashkent, 1964).

[5] A. M. Emelianov, B. B. Golubev. Elektricheskya relaksaciya v visokoomnix materialax. Tezisi dokladov Mejdunarodnoi nauchno-texnicheskoi konferencii, 3-7 oktyabrya 1994 g. (“Obrazovanie”, Sankt-Peterburg, 1994) s. 80

[6] Anant G. Sabins, IEEE Trans. Nuc. Sci, NS-30. (1983) 4094

[7] Daliev X.S., Lebedev A. A., Ekke B. FTP.T21 v, 5, (1987), 836