HANDLING THE PROBLEM OF RADIATION

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Introduction

Electronic systems which encounter a radiation environment give their designers great worries. Semiconductors, renowned for sensitivity to moisture and static, are also greatly sensitive to damage from some radiation environments. The approach is not to try to shut the radiation out - that is often impossible. Instead, one must design to tolerate it.

There is a sequence of several steps to making radiation-tolerant electronics. One estimates the "lifetime dose" - the amount of radiation accumulated over the course of the mission. One then predicts, as best one can, the degradation of performance in the electronic parts and one relates that to the performance of the system. The nub of the matter is to know, within a specified degree of confidence, that the performance of the whole system will not "roll off" too much before the mission is completed. The higher the degree of confidence, the less the worry. REM is able to supply that necessary raised confidence.

REM and Senicoa are part of a larger, well-versed community of parts manufacturers and scientists who, between them, can solve those engineering and design quandaries. The problem is not new to the technology and extensive testing and physics studies have been done by firms like REM, with the support of a whole generation of projects. From this pool of experience come specialists who will measure or model the radiation environment, analyse the damage in the silicon die in question, predict the damage for a given mission and a given circuit and suggest the necessary countermeasures. REM, in its role as dosimetry specialist, has actively measured radiation environments on the ground, in the air and in satellites. The project usually continues with predictions on parts and advice on circuit technology. It may be possible to stop some of the radiation but this is usually only an alleviating measure. Usually, the best solution is the "rad-hard part". This is where a firm like Semicoa comes in. Semicoa has had the government support and private investment funding to take standard transistor designs, modify the production process until a radiation-tolerant part is produced and "qualify" the new product to military or spacecraft standards. What started as a developmental part for one project has now been put on the shelf, a reliable and tolerant product, suitable for future projects to call on.

These engineering process is often called "radiation hardening" - a term deriving from the military description of a well-built fortification as being "hard". The process can often be grafted onto the conventional design routine - *configure, breadboard and test* - used for developing any circuit. The process is perhaps a subset of the more general art of "ruggedisation". As new semiconductors [silicon carbide, graphene etc] and more complex structures are developed [memory chips, microelectromechanical devices etc] research on new radiation effects goes on beside the more routine business - the hardening of systems. Both aspects are spelled out in REM's "Handbook of Radiation Effects".

In this article, we describe several activities linked with radiation hardening, Together they contribute to the design and production of electronics which tolerate a radiation environment. We begin by illustrating some major effects of radiation found in silicon devices, especially the two types of transistor, bipolar and MOS, which perform key operations in circuits.

The bipolar transistor problem

To make radiation-tolerant circuits which employ bipolar transistors, the designer has to understand and accommodate the effects of radiation in this key electronic product. The challenge of the development phase is to make a design which meets the gain degradation incurred in a given mission. The project office will state a dose value which must be tolerated. Then the parts specialist has to set a target for tolerance to this dose, in terms of an amount of gain degradation. He will have to negotiate this with the circuit designer who knows the minimum performance needed in his circuits at the end of the mission. We illustrate the process with one key parameter, GAIN, also known as beta or h_{FE}.

Figure 1 shows the emitter-base region of a planar bipolar transistor with the radiation-sensitive regions indicated. The oxide layer covering this junction is crucial in determining radiation tolerance. The degradation in gain is caused partly by oxide charge buildup, partly by interface damage and partly by defect production in the silicon base region. The degradation is due to the increase in recombination of carriers produced by the three effects just described. A similar set of parameters and physical effects can be invoked to explain the simultaneous increase in other degradation effects - lowering of breakdown voltages and increases in leakages in some places and resistance in others. Luckily, we are the inheritors of about 40 years of research on bipolars in the radiation specialist community, steadily supported by the US government. This has given rise to an understanding of the physics involved and the surprisingly successful APPLICATION of that physics to alleviating the effects. Some specialist manufacturers like Semicoa have applied the research to standard industry parts because there is a market for hardened parts.

In essence, the designer of a hardened transistor has to go to the silicon device processing department and ask the process engineer to modify his industrial device in certain ways. The processing engineer gives him, as best he can, a certain set of silicon structures, dimensions and processing conditions which meet the initial and end-of-life parameters desired by the system designer [see above]. Naturally, such "hardening" does not come without cost to the customer. The making of a radiation-tolerant spacecraft may add 10 percent to the already large cost. The impact of hardening on the parts budget will possibly be even larger.

Meeting end-of-life gain targets for bipolars

This section deals with the quantitative effects of ionizing radiation on bipolar transistors. Figure 3(a) shows the fraction of initial gain, h_{FE} / h_{FE0}, remaining after the irradiation of a comomercial, medium-power transistor over a wide range of doses. The degradation, caused by the effects described in Figure 1, is permanent and grows gradually with accumulated dose. The loss of performance - 70 percent of h_{FE} lost at 10^7 rads - show the potential impact of a radiation environment. The next Figure, 3(b), shows the same data, plotted in a form which is less intuitively understood but which is found more useful for the systematic prediction of performance - a reciprocal form, delta $1/(h_{FE})$. The prediction curve varies systematically with the amount of current flowing in the transistor. For example, for I(C) = 0.1 mA, the curve has the same shape but is shifted upwards.by a factor of about 2.3. The job of the engineer is to use these curves, prepared by firms like REM and Semicoa, and decide how to live with the performance of the system over the life of his equipment. As this indicates, the choices are not "buy hard" or "buy soft" , the alternatives are more subtle and part of the evolution of an overall rugged system.

The MOSFET transistor - a different challenge

In the above paragraphs, we introduced the problem of the original transistor - npn or pnp. The other transistor technology which is used in a great mass of silicon electronics is the metal-oxide-semiconductor (MOS) device. The most common device structure is the field-effect transistor (FET), so that a single device element is kown as a MOSFET. An integrated circuit (IC) made from n and p-channel devices is known as a complementary or CMOS IC. Large discrete MOSFETs now handle high voltages and power and take other specialist roles. The challenge of radiation in MOSFETs is different from that in bipolars.

The owner of REM began work in the firm at which the CMOS IC was first developed and, testing the devices for use in space, realised that there were two opportunities - to develop both super-hard CMOS ICs or the opposite - radiation sensitive detectors of radiation, later called RADFETs. Both of these types of device have come into being and are on the market. Fig. 2 shows a large-geometry p-channel MOSFET, a typical RADFET design, showing the oxide region in which the radiation-induced charge is trapped and the silicon channel in which it can be sensed. In the high-density super-hard, modern CMOS IC, these regions have been shrunk to submicron size where the significance of the charge is smaller.

Research in radiation effects in complex CMOS ICs continues but there are also thousands of off-the-shelf types of CMOS IC and Power MOSFETs which have been qualified for operation in radiation [see web page ...].

So much for super-hard MOS technology. As for the super-soft MOS, the detector of radiation, the REM RADFET was first made for the European Space Agency by REM in 1975 but is now also used in many other spheres. As already explained, the RADFET design centres on the oxide film lying between the input and output - in this case the Source and the Drain - see Fig. 2. The RADFET chips made by REM's processing contractor carry a gate oxide of specially-chosen recipe and thickness laid out on a mask designed for purpose. As in Fig 1, the generation of fixed oxide charge in the oxide is the mechanism of action but, in the RADFET, the quantity of charge sensed gives a simple direct-current value for ther amount of rasdiation received. The tiny device - thousands of times smaller than a Geiger counter - can detect a dose as small as 1 rad (0.01 Gray) and go where such massive, power-hungry instruments can never go, including the outer planets and most places within the human body. The quantitative effects of radiation on MOSFET logic are dealt with in REM's "Handbook of Radiation Effects". The responses of RADFETs are described in detail in REM's data sheets - see link.

Conclusion

The activities of a radiation hardening expert range across the measurement of radiation, the testing of devices in radiation sources and physical analysis of the effects of a radiation environment. REM offers consultancy in all of these areas and also designs and sells unusual MOSFETs for an unusual purpose - the sensing of radiation. With firms like Semicoa REM can also, in addition, specify suitably hardened silicon devices for a project. The industries and laboratories within which we find our customers include those designing or building spacecraft, avionics and nuclear reactor equipment; plus a host of more limited terrestrial activities including high-energy accelerator research, radiotherapy, radiography, materials processing and analysis.

References

General

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A.G. Holmes-Siedle, "Predicting end-of-life performance in space". Radiation Phys. and Chemistry, 43, 57-77 (1994).

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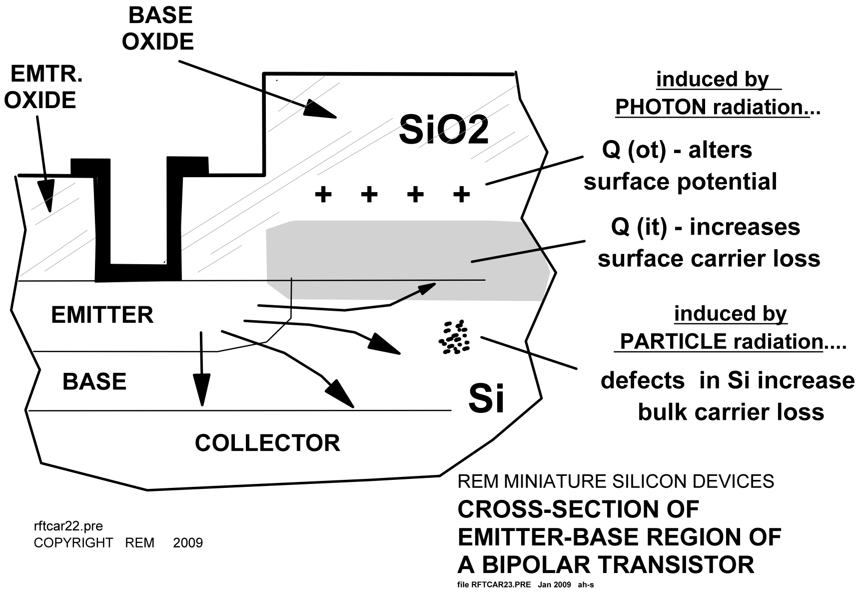

Fig. 1 A cross-section of the emitter-base region of a planar bipolar transistor showing several effects of radiation on the structure. Positive charge, Q(ot), alters fields and potentials. Iinterface effects and also defects in the bulk of the silicon h increase carrier loss

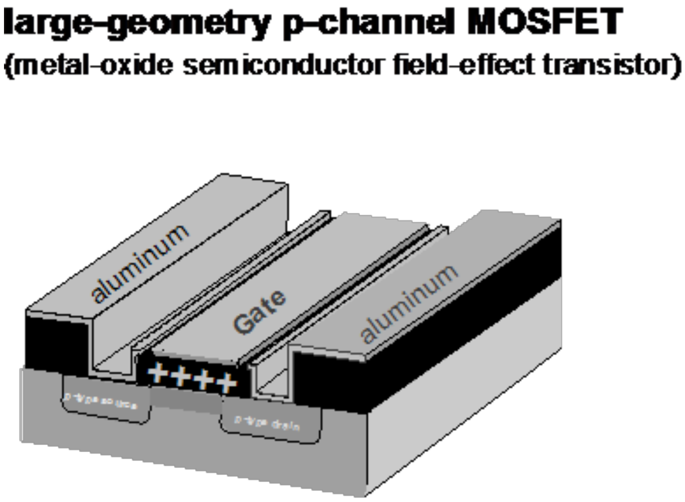

Fig. 2 shows a large-geometry p-channel MOSFET, showing the gate oxide region in which radiation-induced positive charge is trapped. In the RADFET, the silicon channel underneath the oxide senses the amount of charge.

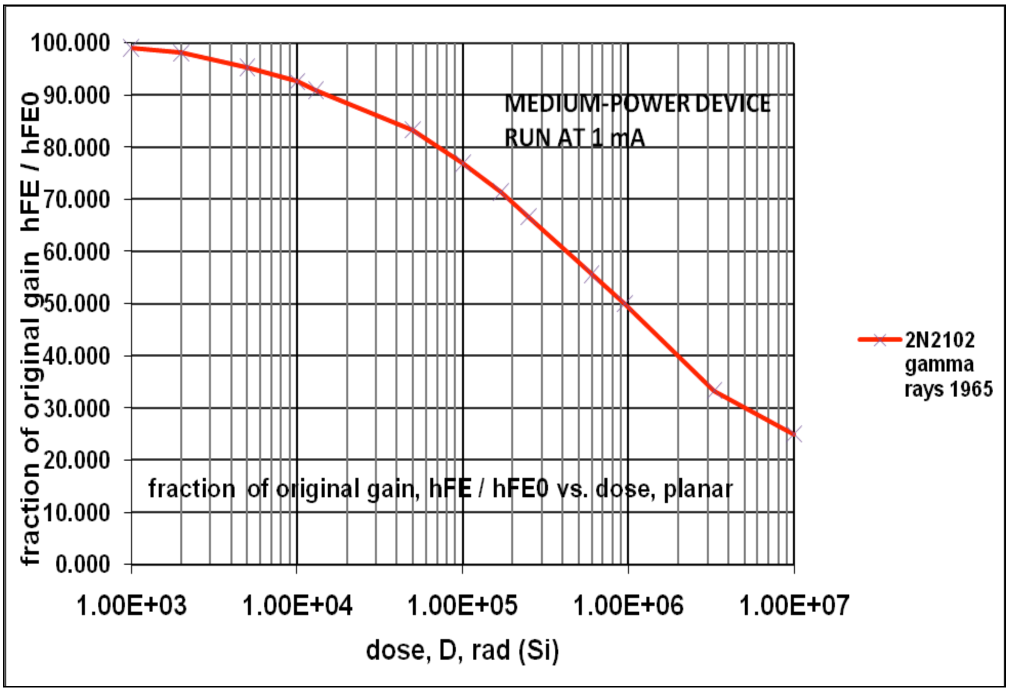

Fig. 3 Meeting the end-of-life gain targets. (a) Plot of fractional loss of gain versus dose

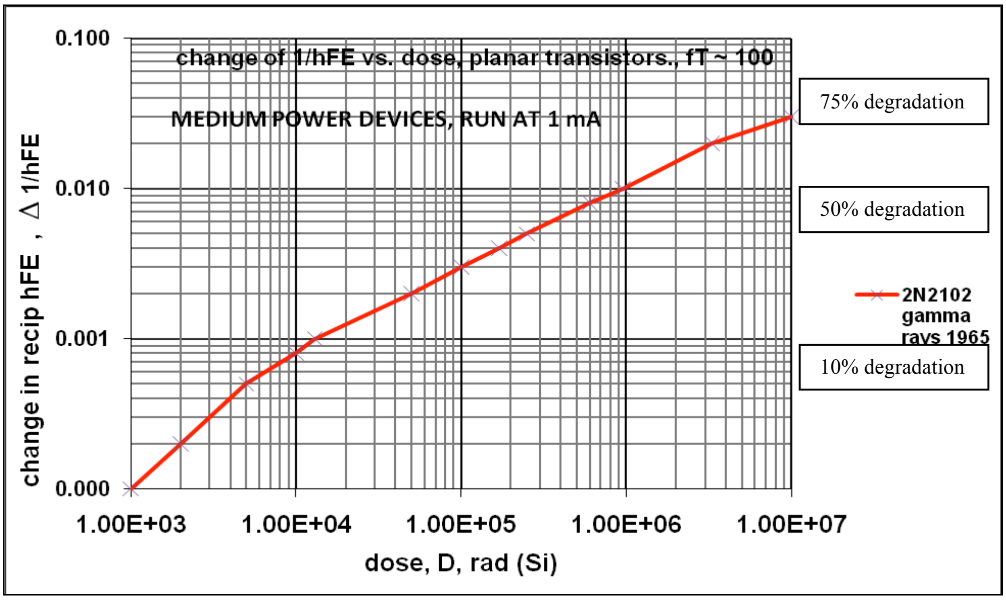

Fig. 3(b) Model for plotting gain degradation trends and targets.