

Ionizing radiation effect on 10-bit bipolar A/D converter

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Abstract In this article, radiation effects and annealing characteristics of a bipolar analog-to-digital converter (ADC) are investigated in different biases and dose rates. The results show that ADC is sensitive to both the bias and dose rate. Under high-dose-rate irradiation, the ADC functions well, while under low-dose-rate irradiation, the parameters of ADC change obviously at low dose level, and the damage is significant at zero bias. Combining the fringing field with the space charge model, the underlying mechanism for this response is discussed.

Key words Bipolar Analog to Digital converters; ⁶⁰Co γ Radiation; ELDRS; Bias condition.

1 Introduction

As an interface circuit between analog and digital signal systems, analog to digital converters (ADC) are extensively used in various electronics systems. However, the electric parameters of an ADC in spacecrafts can be affected by ionizing radiations, even causing its function failure^[1–4]. The parameter degradation is resulted from shifts of the threshold voltage of internal MOSFET in the digital part and changes in analog parameters. Such degradation may be a threat to the reliability of the electronic systems of spacecrafts. The radiation effect and radiation hardening technologies have been studied in many countries, but most of the researches were focused on total dose effects on MOS devices, while the radiation effect of different irradiation conditions on bipolar ADC devices was not studied as frequently. So far, sensitive parameters and damage mechanisms of ADC are not clear, and space applications of ADC are limited in China. Therefore, it is especially important to study radiation effects on ADCs under different radiation conditions.

In a satellite, not all the circuits are in their

working status at a time, but radiation sensitivity of a circuit is closely related to its working status. So, different bias conditions must be considered when evaluating a circuit in laboratory. It was widely reported that most bipolar linear integrated circuits exhibited enhanced low-dose-rate sensitivity (ELDRS) effect^[5–9], such as operational amplifiers, comparators, voltage regulators, etc. Then, would a bipolar ADC have an ELDRS effect, how does it suffer under different dose rates and biases, and what are the radiation damage mechanisms? In this paper, AD571, which is widely used in spacecrafts, is chosen to answer these questions. The bipolar ADCs were irradiated at various dose rates and biases. Obvious ELDRS effect and remarkable damage differences under different biases were found. The radiation damage mechanisms are discussed.

2 Materials and methods

The samples are 10-bit successive approximation bipolar analog-digital converters of AD571 (Analog Devices Inc., USA), consisting of DAC, voltage reference, comparator, successive approximation register, clock, etc. They were irradiated in ⁶⁰Co γ -ray

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sources of 1×10^{15} Bq and 3.7×10^{13} Bq at Xinjiang Technical Institute of Physics and Chemistry, at dose rates of 0.5 Gy(Si)/s (high dose rate) and 0.5 mGy(Si)/s (low dose rate), calibrated with CaF_2 and LiF thermal luminescent dosimeters, respectively. The samples, shielded in Pb/Al boxes, so as to avoid low-energy scattering and dose-enhancement effect, were divided into two bias groups. The Group 1 ADCs were in working status supplied with normal voltages (5 V) to the digital and analog parts, respectively. The Group 2 ADCs were in zero bias, with all pins being grounded. The ADCs, irradiated at high or low dose rate, were annealed under the same conditions, while they bias conditions were kept the same during the annealing.

The bipolar ADCs were measured before and after irradiation on AMIDA3000 integrated circuits

analyzer (AMIDA Technology Corp. Taiwan) for the following parameters: differential nonlinearity (DNL), integral nonlinearity (INL), power consumption (P_c), gain (E_g), input offset current (I_{os}) and zero offset (E_0). All the measurements of an irradiated ADC were completed in 20 min after irradiation.

3 Results

Radiation responses of the bipolar ADCs were observed under different conditions. It was found that AD571 was quite sensitive to the γ -ray irradiation, with most of the parameters being degraded to certain degrees. The DNL versus total dose and annealing time for the ADCs irradiated at the high and low dose rates is shown in Fig.1.

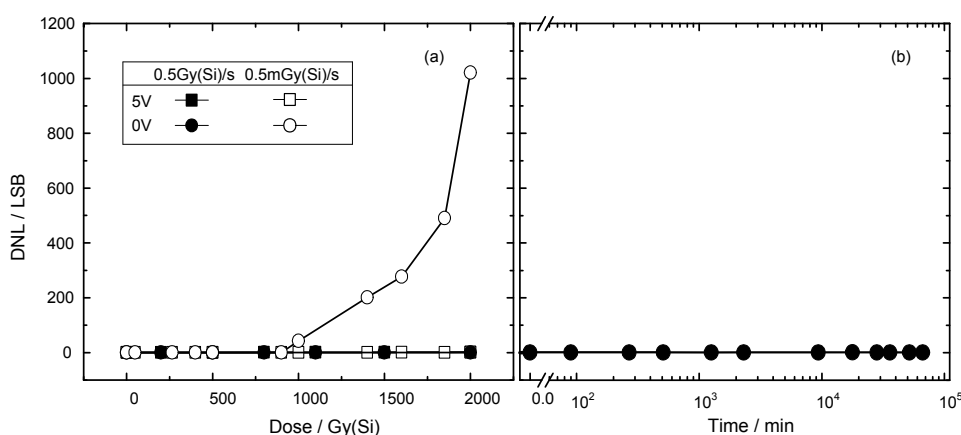


Fig. 1 The DNL of A/D converter versus (a) total dose and (b) annealing time at room temperature.

From Fig.1(a), the radiation responses of DNL differ greatly under different dose rates and biases. The DNL is not sensitive to the high-dose-rate irradiation for the ADCs biased at zero or 5 V. However, for the low-dose-rate irradiated and zero biased, the DNL begins to increase sharply at the total dose of 800 Gy(Si) towards a saturation at 2000 Gy(Si), where the function of AD571 failed; whereas for the low-dose-rate irradiated and 5-V biased, the DNL responses is not sensitive, just like the high-dose-rate irradiated. In Fig.1(b), the ADCs, irradiated to a total

dose of 2000 Gy(Si) at the high or low dose rates, and biased at zero or 5 V, were annealed at room-temperature for different hours. The DNL responses do not change much for all the ADCs.

Figs.(2) and (3) show the radiation responses of INL and E_g , respectively. The radiation response and annealing characteristics are similar to DNL. The only difference is that E_g gradually decrease with the total dose accumulation. At the total dose of 800 Gy(Si), E_g begins to decrease sharply towards a saturation at 1000 Gy(Si), where the AD571 failed.

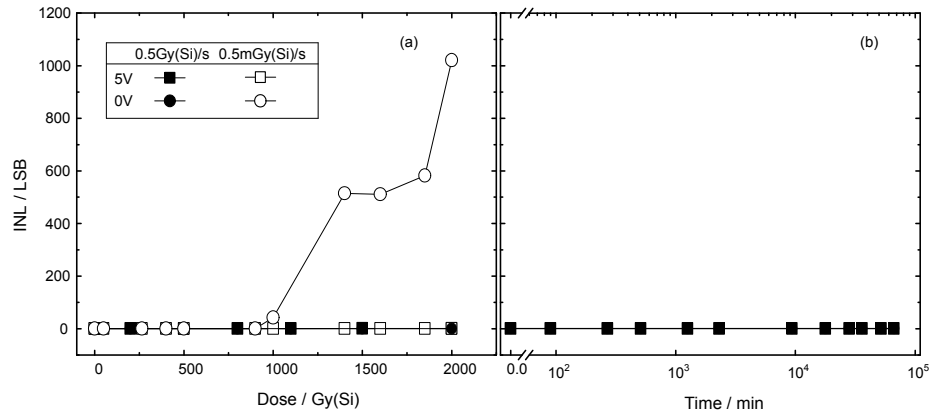


Fig. 2 The INL of A/D converter versus (a) total dose and (b) annealing time at room temperature.

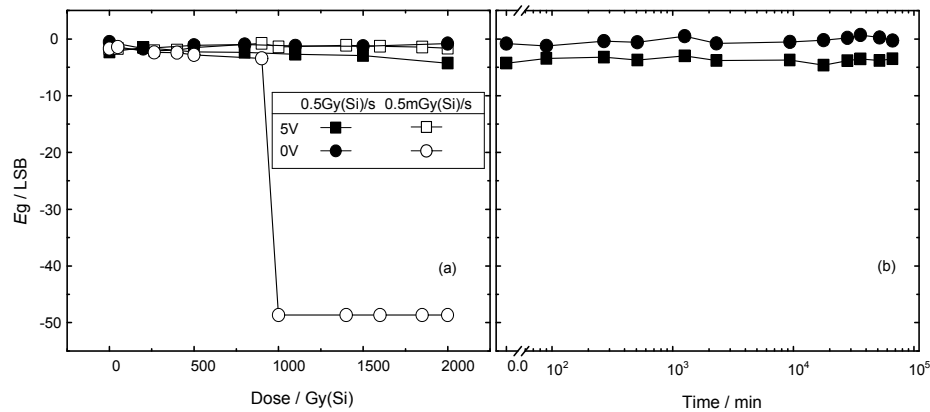


Fig. 3 The E_g of A/D converter versus total dose (a) and annealing time at room temperature (b).

Fig.4 shows the radiation response and room-temperature annealing of power consumption (P_c). The P_c decreases gradually with the dose, but not saturation of the P_c is seen at 2000 Gy(Si). However, the decrease rate does not differ much for the high-dose-rate irradiated ADCs biased at zero or 5 V, whereas the P_c of the low-dose-rate irradiated ADC

biased at zero decreases greatly even at a very low total dose, causing function failure of the circuits.

As described above, 10-bit ADC is sensitive to both the dose rate and to bias. Under 5-V bias, the dose-rate effect is not remarkable, while obvious ELDRS effect occurs at zero bias.

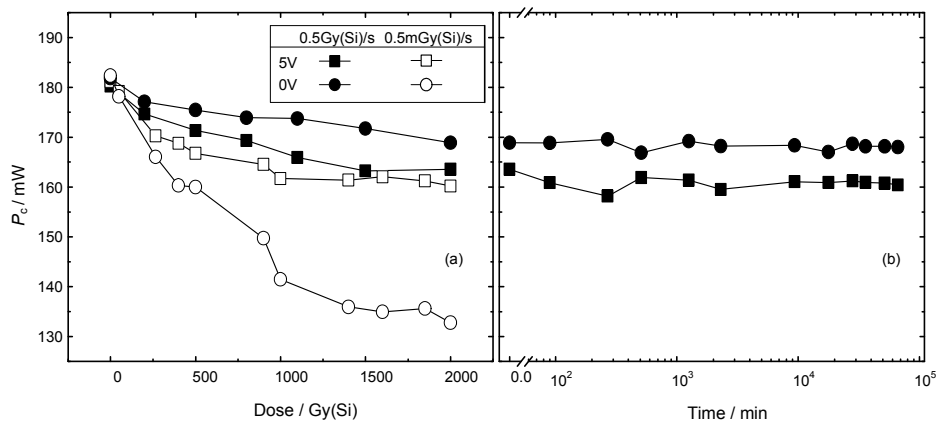


Fig. 4 The ΔP_c of A/D converter versus total dose (a) and annealing time at room temperature (b).

4 Discussions

In ionizing radiation environment, electric parameter degradation of bipolar ADC is determined by the performance of transistors in ADC. From our previous works^[7–9], current gain of the transistor decreases, and leakage current increases, resulting in the decline of frequency and precision, and lock of the clock. These would cause an ADC to fail. The damage differences for different dose rates and biases can be explained by space charge model^[10, 11] and the fringing field^[12].

4.1 Dose-rate effect

According to the ionizing damage mechanisms of the bipolar device, the parameter degradation and function failure can be attributed to the accumulation of oxide-trapped charges and interface trapped charges.

A great number of oxide trapped charges are produced in the base oxide layer of the high dose-rate irradiated ADCs^[7,9]. The charges form a space field in the oxide layer to block the radiation-induced holes and hydrogen ions to reach the Si-SiO₂ interface. After a long time, only a few radiation-induced holes and hydrogen ions reach the Si-SiO₂ interface. Under the low dose-rate irradiation, however, the radiation-induced oxide charges are fewer, and the space field formed by

the charges is weaker. Thus, the radiation-induced holes and hydrogen ions have enough time to transport to the Si-SiO₂ interface and react with the dangling bonds there to generate interface trapped charges. These interfaces trapped charges can become the recombination centers in the base surface. Consequently, they increase the excessive base current, decrease the current gain of transistors, and enhance the radiation damage at low dose-rate. These are the reasons why the low- dose-rate irradiated ADCs suffer greater damage than the high-dose -rate irradiated (Figs.1–4).

4.2 Bias effect on damage differences

A transistor consists of two back to back p-n junctions. There is a space charge field that is a build-in electric field near the p-n junction. The radiation responses of bipolar transistor are closely related to the emitter-base junction bias. There is a SiO₂ layer on emitter junction, as seen from the production technology of the transistor (see the structure in Fig.5). The build-in field in base-emitter junction can form a fringing field in the oxide layer. Fringing field closely depends on the build-in electric field. The build-in field at forward bias is weaker than that at zero bias, which creates a weaker fringing field^[12].

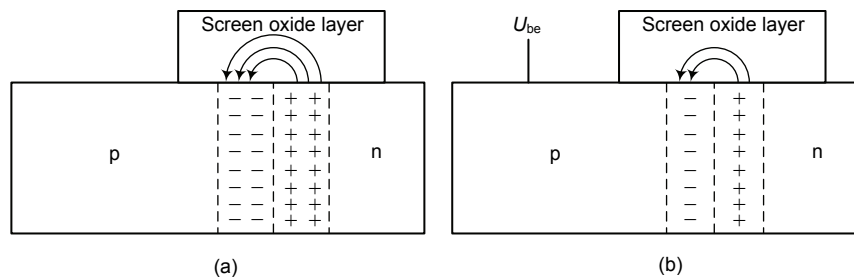


Fig.5 The space-charge field in p-n junction zero bias and (b) forward bias.

Distribution and transportation of the charge are affected by both space-charge field and fringing field in the screen oxide layer. Radiation-induced charges have certain modulation to fringing field. Under high-dose-rate irradiation, the stronger space field formed by radiation- induced charges shields the fringing field^[10]. Therefore, DNL, INL and E_g are all not sensitive to ionizing radiation at zero bias or 5-V bias. However, large charges would be induced by the low-dose-rate irradiation. When the base-emitter

junction is positively biased, less holes and hydrogen ions transport to the Si-SiO₂ interface for both npn transistor and pnp transistor by the weaker fringing field, as can be seen in Fig.5. Thus, the oxide-trapped and interface-trapped charges would be less than that at strong fringing field. At zero bias, the build-in field and fringing field are greater than positive bias. There will be more radiation-induced holes and hydrogen ions migrating to Si-SiO₂ interface to form interface traps. The excess base current of bipolar transistors is

direct proportional to interface traps. The buildup of interface traps is the main reason of ELDRS. Thereby, zero bias is the worst for low-dose- rate radiation. Therefore, the damage to the differently biased ADCs differs as shown in Figs.1–4.

It can be seen that the change of power consumption of ADC is different to others in Fig.4. As the total dose irradiated accumulating, it decreases gradually. This may be attributed to radiation response of pnp transistors in ADC. The existence of radiation-induced combination centre and interface state, especially latter, cause the current gain of bipolar devices decrease. Consequently, it causes the decrease of the power consumption. Furthermore, the collector current of transistor and the supply current of bipolar operation amplifier all exhibit a similar phenomenon as research reported^[11, 13].

5 Conclusions

Bipolar ADC is sensitive to ionizing irradiation, with degradation of different extents for parameters of DNL, INL, E_g and P_c . The parameter degradations of ADC irradiated at low dose rate are more obvious than the high-dose-rate irradiated. The AD571 obviously exhibits ELDRS effect.

The responses of the bipolar analog-digital mixed circuit show great differences under different biases. Under low dose rate irradiation, the worst damage occurred at zero bias.

In space radiation environment, the bipolar ADC exhibits ELDRS effect and the response of parameters of ADC are different. So, in selecting and

assessing this kind of devices, the dose rate and bias conditions should be considered synthetically to ensure reliability of the spacecrafts.

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