Réponses en dose totale des circuits prédiffusés programmable par l'utilisateur (FPGAs) d'Actel 102OB et 1280A

Total Dose Responses of Actel 1020B and 1280A Field Programmable Gate Arrays (FPGAs)

Richard Katz,* David Shaw** and Gary Swift**

Résumé:
L'irradiation gamma et le recuit d'un grand nombre de CPPU d'Actel ont été effectués avec des mesures de courant in situ. Les variations de lot à lot, de pike à pike, ainsi que clans le brûlage, ont été mesurées. Les découvertes comprennent un mécani sme de défaillance totale brusque ainsi que des effets d' intensité de dose minimale.

Abstract:
Gamma irradiation and annealing of a large number of Actel FPGAs with in-situ current measurements were performed, Lot -to-lot, part-to-part, and burn in variations were measured. Findings include a catastrophic failure mechanism and minimal dose rate effect s.

* NASA/ Goddard Spaceflight Center

** Jet Propulsion Laboratory
California institute of Technology
4800 Oak Grove Drive, MS: 303-220
Pasadena, CA 91109

Voice: 818-353-5059
Fax: 818-393-4559
Email: gary.m.swift@jpl .nasa.gov

I. INTRODUCTION

Designers of circuits for deployment in space arc kccnl y aware of the advantages afforded by modern, commercial (not radiation-hardened) VLSI devices, such as memories and FPGAs: e.g., speed, density, and power consumption.. Often there arc a sufficient number of vendors that fortuitously radiation-tolerant devices can bc found. Gate arrays arc particularly attractive to designers since they can bc used to replace large numbers of discrete logic devices. Field programmable (the alternative is mask programmable) offer additional advantages in cost and schedule. As a result, a number of spacecraft incorporate Actel FPGAs.

Viable alternative commercial FPGA manufacturers and technologies suitable for space applications are not yet available, nor arc any military or radiation hardened devices. The silicon area in a typical FPGA is about half devoted to logic elements and half programmable interconnects that select logic functions and route signals internally. There arc two major types of interconnects: one-time. programmable anti fuses and reusable SRAM-based signal multiplexers. Commmercial SRAM type FPGAs, while very popular for ground-based designs and available from several manufacturers, arc difficult to usc in space because they arc very SEU-soft, i .c. protons and heavy ions cause SEUS that randomly redefine the circuit functionality. (Unfortunately, Harris has announced that they have abandoned an effort to provide a SEU-hardened SRAM-based FPGA.) Actel uscs an oxide-nitride-oxide (ONO) sandwich for the antifuse dielectric as the basis of their one-time programmable FPGA. Very heavy ions have been shown to cause undesired, partial connections for these ant ifuses, but the predicted rate of occurrence is so low that they may bc usable for most space missions [1]. It remains to bc seen if amorphous silicon's usc as an antifuse dielectric, the .so-called metal-to-metal ant ifuse, eliminates this problem. (Quicklogic has a commercially available family of FPGAs with metal-to-metal ant ifuses, but their single event latchup cross section is so high (greater than 103 cm^2 pcr device [7]) that a determination is precluded, as well as making thcm unattractive for space applications.) (A Phillips Lab-sponsored effort by Loral and Actel to build radiation-hardened versions of two Actel FPGAs is underway and includes ant ifuse changes intended to eliminate or reduce the chances of ion-induced connections.)

The unavailability or unattractiveness of alternatives has resulted in a great deal of study of Actel FPGAs [2-5]. The present work concentrates on the total dose response of the current generat ion (one micron feat urc size) of two popular devices: the -2000-gate A 1020B and the ~6000-gate A 1280A. By studying a large number of samples, this study is uniquely able to draw conclusions relative to several parameters: lot-to-lot variations, the effect of burn-in, dose rate response differences, and bias effects. Since these arc commercial devices, i.e., their radiation tolerance is not by design, some of the results arc rather surprising.

II. TEST METHODOLOG%

Test Devices. The 1020-famil y of -2000-gate FPGAs has progressed through two generations of feature sizes, the original 2.0 p and a 1.2 μ shrink, to the current 1.0 μ device used in this testing. While neither of the earlier devices exhibited single event latchup (SEL), the A 1020B is known to have a moderate SEL susceptibilit y [6] and recently heavy ion testing revealed clock t rcc upsets [7]. '1'bus, space applications may require circuitry for latchup mitigation and/or bursts of upsets. Thirty-six test samples with twenty four of thcm burned in, drawn from two lots were tested for this study. With a single lot exception [4], all feature sizes of 1020-family FPGAs have been found by previous stud ics to bc within specifications for at least 50 krad(Si), some over 200 krad(Si) [2-5].

Similarly, the 1280 family was originally a 1.2 p design and is now available as a 1.0 μ shrink, the device tested for this work. Neither latchup nor clock upsets have been reported for either of these devices. 48 samples from three lots (about two thirds of thcm arc burned in) arc being tested. Again with a single lot exception [4], previous studies have found 1280-family devices to function within specifications for at least 8 krad(Si), often over 25 krad(Si) [2-5]. It should bc noted that although the feature size is the same as later 1020-family devices, the 1280-family is a later design using different design rules and incorporating numerous improvements, e.g. the charge pump is improved. The wide range of total dose results from different testers may be due to different test programs and methodologies, but is likely due to lot variations since one tester [4] saw a wide variation between lots using the same test procedure. As will be seen, this study, the first with a large sample size, supports that conclusion.

Test program. The test patterns wcc meant to exercise the typical functions of the devices. For example, the 1280 test chip pattern was programmed into four basic sections: (1) combinatorial logic, (2) flip-flops, (3) input/output latches, and (4) shift register and counter. All functional and parametric testing was carried out on automated VLSI testers, either a Sentry S-50 or Advantest 3'3342. The test devices were irradiated using Co^{60} at selected dose rates from 0.01 to 50 rads per second and subjected to several days of room temperature or 100° C. annealing under bias. Some of the tests were run with dynamic bias during irradiation, but most were static biased.

III. Test Results

Shown in Figure 1 are examples of during-irradiation responses of supply current for a representative A 102013 and A 1280A under static bias. The comparison clearly shows that the side effect of the "improvements" in the A 1280A is a significantly degraded total dose response. Also, the A 1280A begins to draw significant current well before failure. The significant jump in current to more than the power supply set point of 800 mA at -21.5 krad(Si) likely marks major functional failure. This large jump is a consistent characteristic of these experiments and has occurred as low as 12 krad(Si). Note that, though striking, this is similar to the large increase reported in Reference 4 when irradiated parts were elevated in temperature (although radiation alone was the cause here and only the A 1280A exhibited the phenomenon). The design change most likely to account for this response is the two-stage bias generator which lowers by over an order of magnitude the supply current for an unirradiated A 1280A relative to the A 1020B (even though there are three times as many gates). This charge pump's purpose is to ensure that the isolation FETs (needed for programming) are fully on for normal part operation, As dose degrades its output capacity and increases the drive needs of the -104 transistors, a significant number of the logic arrays' CMOS pairs are both on, at least partially, and thus draw significant current. About a thousand of these drawing a significant fraction of a mA is enough to account for the largest currents observed (almost 1.5 A). This is consistent with one of the proposed explanations and the accompanying Spice model of Reference 4. An experiment to determine if dynamic bias significantly increases the radiation tolerance is planned in time for the conference.
Parameters other than supply current show a lesser response to dose, usually within specification. These include input leakages, output voltages, and propagation delays. Figure 2 is a notable example for the A 1020. The increase in propagation delay seen during the high temperature anneal period is less than the specified maximum of 150 picoseconds, but is large enough to cause problems with unintentionally marginal designs that work fine before irradiation. Additionally, functionality was checked for the range of 4.5 to 5 .5V and at two clock rates. The table below summarizes the variations in a selected few parameters. This will be updated as more parts are tested.

TABLE
First Failures for Selected Parameters and the Corresponding Radiation Levels (in krad(Si))

	functionals	ICCH	VOH
A1020B (lot A)	pass: 30 krad fail: 4 of 6 @ 50	70 to 250 mA @ 50	~ 0 V, all 6 @ 50 krads
A1020B (lot B)	pass: 20 krad fail: 5 of 6 @ 30	23 to 44 mA @ 30 krad	~0 V, 2 of 6 @ 30 krad
A1280A (lot A)	pass: 10 krad fail: 5 of 6 @ 15	90 to >250 mA @ 10 krad(Si)	-O V, 5 of 6 @ 15 krads
A 1280A (lot B)	pass: 20 krad	>64 mA, all 6 @10 krad(Si)	pass: -4.2 V, all 6 @ 20

Dissecting these results leads to the following tentative conclusions: (1) lot-to-lot variation is significant, (2) part-to-part variation is also notable, though smaller, and (3) differences between burned in parts and those not burned in arc smaller, possibly insignificant.

Since many missions conserve power by leaving systems off for a significant fraction of the time, an experiment was undertaken to determine if an unbiased A 1280A's dose response was less. Figure 3 is the bias current response during irradiation, and it is clear that dose accumulated while unbiased is less severely damaging. A follow-up irradiation under bias shows the current increase earlier than an unirradiated device, as can be seen in Figure 4a. Figure 4b shows the during-anneal ing response of the static bias current. While the rapid annealing was expected, the implication that unbiased irradiation causes latent damage or somehow increases the biased radiation susceptibility was not. Further, experiments are required to determine the reproducibility of this observation.

IV. CONCLUSIONS

The A 1020B is almost as tolerant to dose as previous (larger feature size) devices. The "enhanced" charge pump of the A 1280 greatly increases its radiation susceptibility and can be expected to draw significant current (> 100 mA, static) after only a few krad(Si), well before functional failure at 10-20 krad(Si). The dic shrunk version, the A 1280A, is slightly softer. Both device types show significant part-to-part and lot-to-lot variation. The effects of burnin on the dose susceptibility, if any, arc smaller than part-to-part variation. Irradiating an A 1280A without bias significantly lowers the dose response, although it appears as if it may enhance the effects of subsequent biased irradiation. The charge pump damage of the A 1280A anneals readily. Thus, it is expected that ongoing low dose rate testing will reveal a significant decrease in susceptibility for the same total dose.

V. REFERENCES

[I] G. Swift and R. Katz, "An Experimental Survey of Heavy Ion Induced Dielectric Rupture in Actel FPGAs," submitted to RADECS '95.

[2] R, Katz, R. Barto, P. McKerracher, B. Carkhuff, and R. Koga, "SEU Hardening of FPGAs for Space Applications and Device Characterization," *IEEE Trans. Nucl. Ski. 41, 2179-2186,* Dec. 1994.

[3] R. Koga, W. R. Crain, K. B. Crawford, S. J. Hansel, S. D. Pinkerton, and T. K Tsubota, "The impact of ASIC Devices on the SEU Vulnerability of Space-borne Computers, *IEEE Trans. Nucl. Sci.* 39, 1685-1692, Dec. 1992.

[4] Field Programmable Gate Arrays: Evaluation for Space-F1ight Applications, JPL Publication 92-22, September 15, 1992

[5] G. K. Lum, R. J. May, and L. E. Robinette, "Total Dose Hardness of FPGAs," *IEEE Trans. Nucl. Sci.* 41, 2487-2493, Dec. 1994.

[6] R. Koga, S. J. Hansel, W. R. Crain, K. B. Crawford, and J. F. Kirshman, presentation on "Comparison of SEU and Latchup Susceptibilities of Actel's 2.0, 1.2, and 1,0 micron CMOS FPGAs," Ninth SEE Symposium, Manhattan Beach, Cal if., April 19-21, 1994 (scc also [1] and [6]).

[7] Unpublished JPL/GSFC test data taken at Berkeley 88" Cyclotron, September 21-22, 1994, and Brookhaven Single Event Test Facility, December 6-7, 1994.

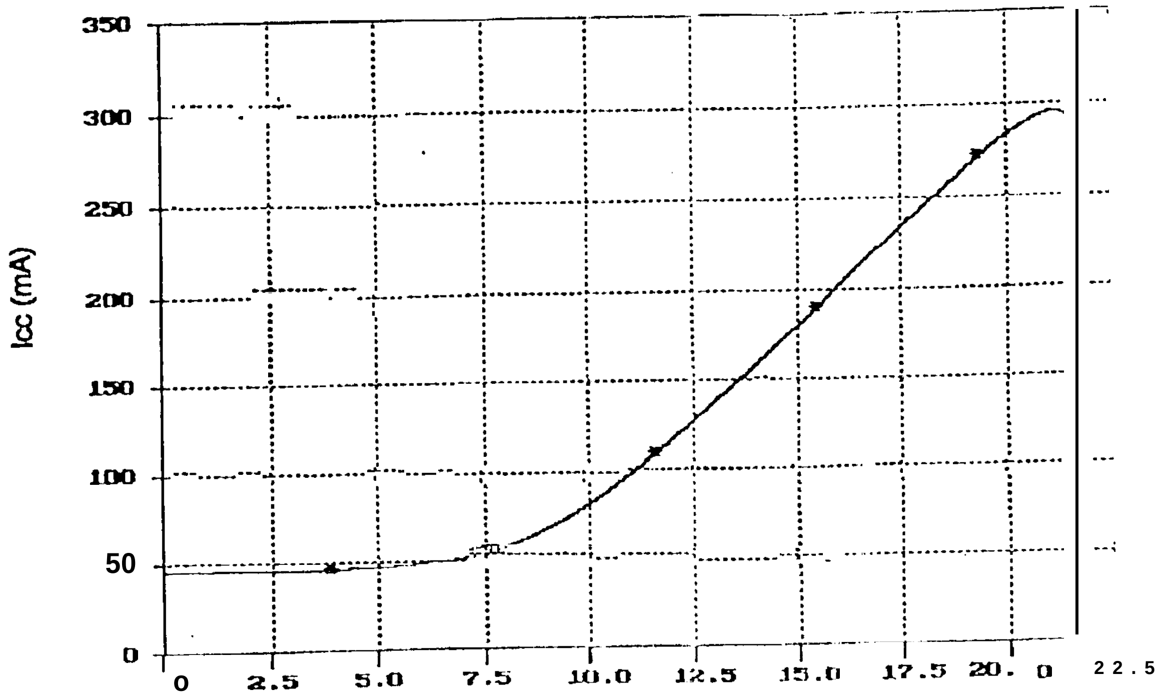

Figure 1a. Supply current for an A 1280A (s/n: 305, burned in) during irradation with 5V static bias at 0.3 rad(Si) per second.

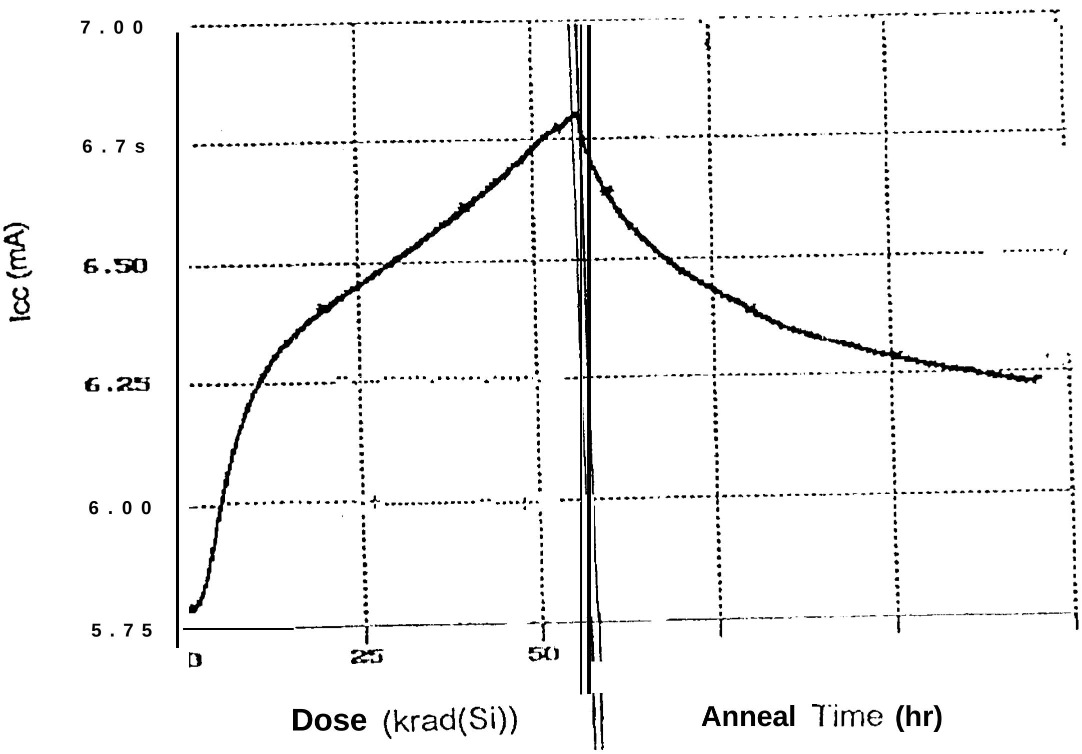

Figure 1b. Supply current for an Al 020B (s/n: 509, burned in) during irradiation]] with 5V static bias at 0.3 rads(Si) per second.

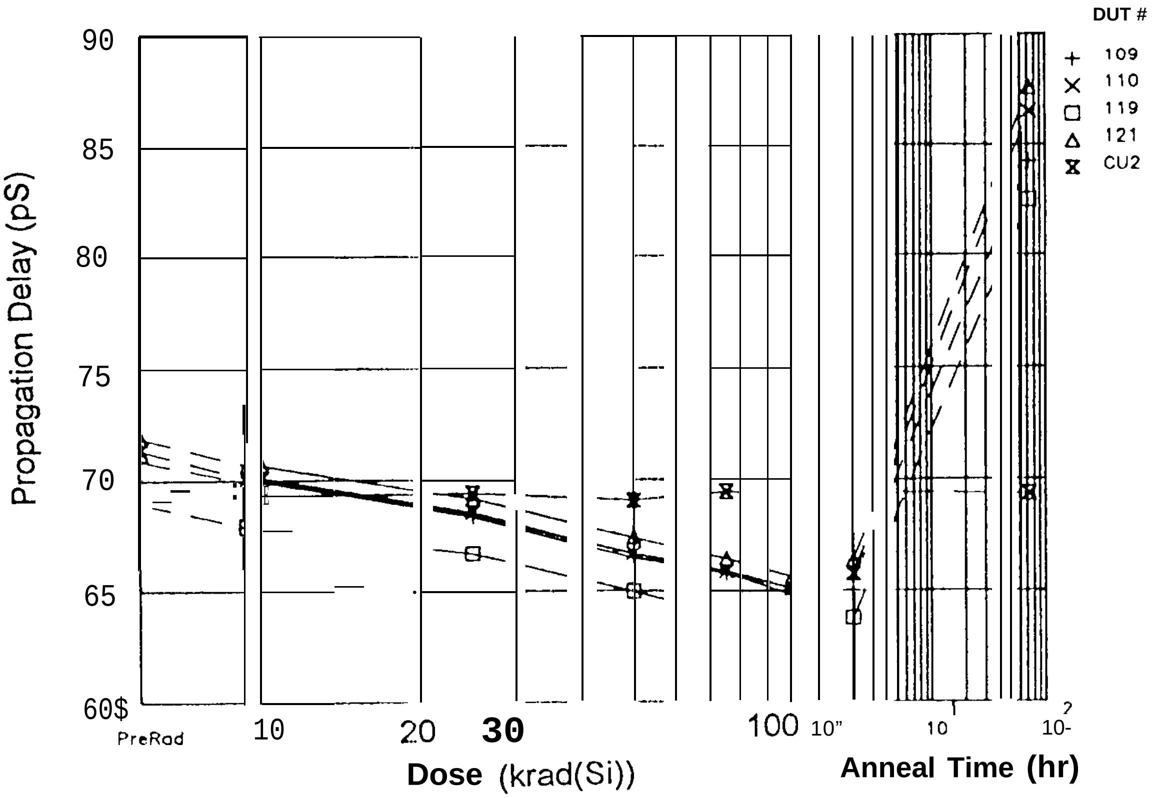

Figure 2. Propagation delay of four A 1020s during irradiation at 10 rad(Si) per second followed by a 72 hour accelerated anneal at 100 degrees C.

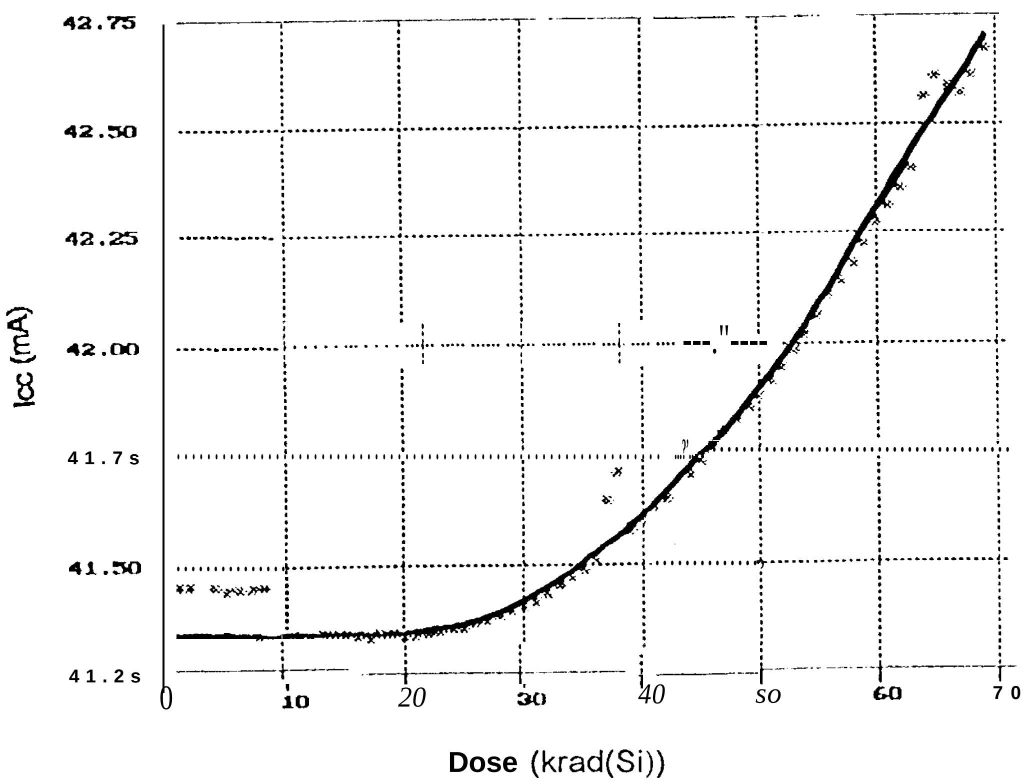

Figure 3. Supply current for an A 1280A (s/n: 158, not burned in) with no bias during irradiation (during measurements, bias' 5V) at 0.3 rad(Si)/sec.

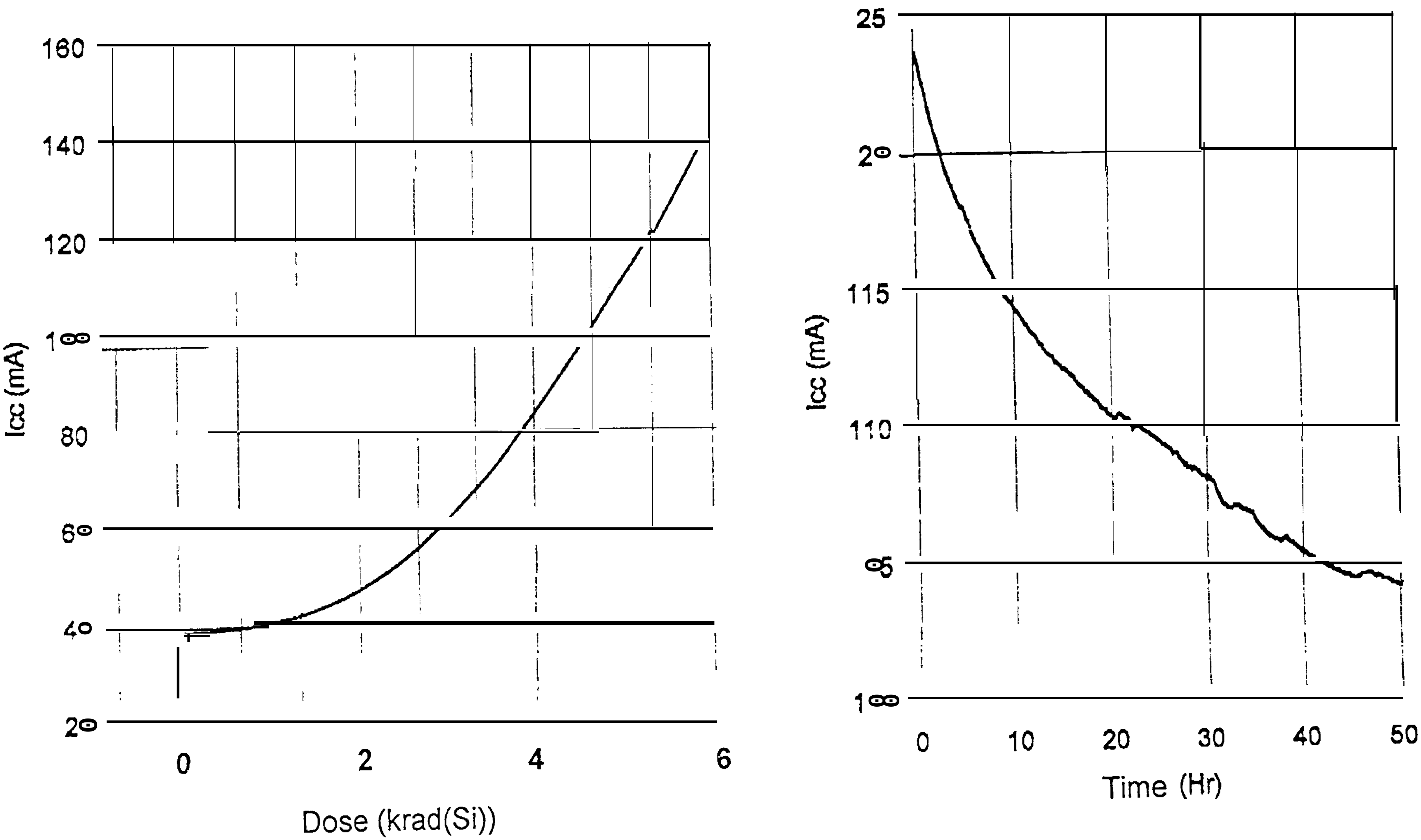

Figure 4. Supply current for an A1280B (s/n: 158, not burned in) during follow-up irradiation with 5V static bias at 0.1 rads(Si) per second on the left and during the subsequent room temperature anneal on the right.