Radiation Hardness Total Ionizing Dose Testing of Intel Wolfdale Processor

Abstract:
Intel's Wolfdale microprocessor, fabricated in 45nm CMOS technology with "Hi-K" gate dielectric, was tested for Total Ionizing Dose (TID) radiation hardness. This report summarizes the results. The units were irradiated at a gamma source facility in November and December 2008 and periodically tested for functionality. At the end of irradiation they were shipped to Intel for full parametric characterization.

Total Ionizing Dose (TID) Experiment:

Description of Devices under Test (DUT)
The Wolfdale is a Core 2 Duo microprocessor in a 775 pin Land Grid Array (LGA775) package, having contact pads on the under surface and a metallic heat removal cover on upper surface. The parts were manufactured with Intel's Hi-K 45nm semiconductor technology and were not modified (specifically, they were not delidded) for this test.

All DUTs used in this testing were acquired directly from Intel.

10 DUTs were allotted for this test. Nine were irradiated and one served as a control part. The DUTs each had written on their top surface a number from 1-10 in permanent marker. (Specific DUTs will be referred to as, e.g., DUTID 1) Internal Processor ID number was not used for these tests.

DUTID 10 was assigned to be the unirradiated control which was treated identically to the other DUTs except for irradiation and was tested whenever any of the other parts were tested.

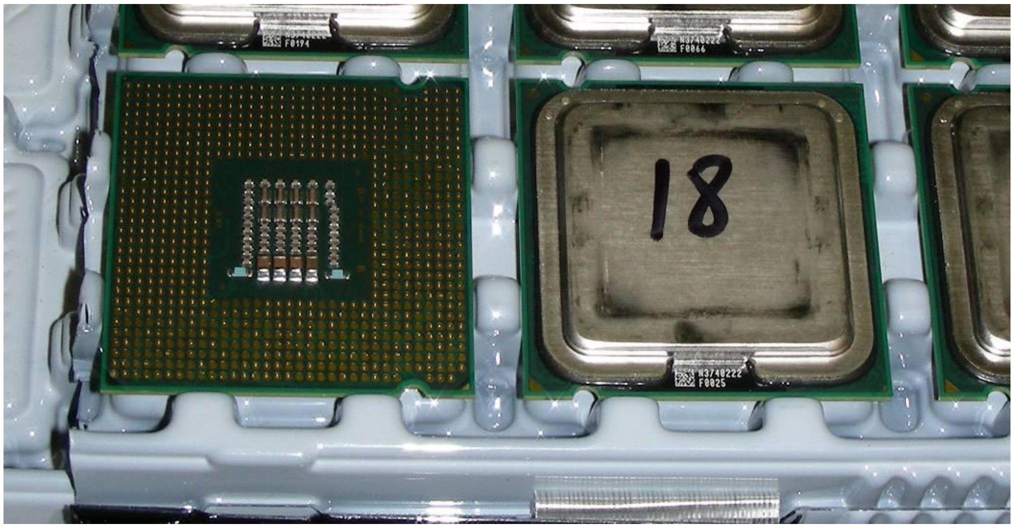

Figure 1. Two Wolfdale Processors, Showing Contacts And No Production Markings.

Initial characterization of Units

Being Intel-supplied, these units were found suitable for testing by Intel but no specific results were available. The parts were tested for functionality in a motherboard, as described below, before any irradiation took place.

Test Hardware Setup

Irradiation Setup

The DUTs were installed in an Intel-provided burn-in board and experienced whatever control and load settings that this board provided. The board fit 18 DUTs so a center group of three sockets were selected for this test. Each DUT only ever occupied one socket; as they were removed and reinstalled they always returned to the same socket.

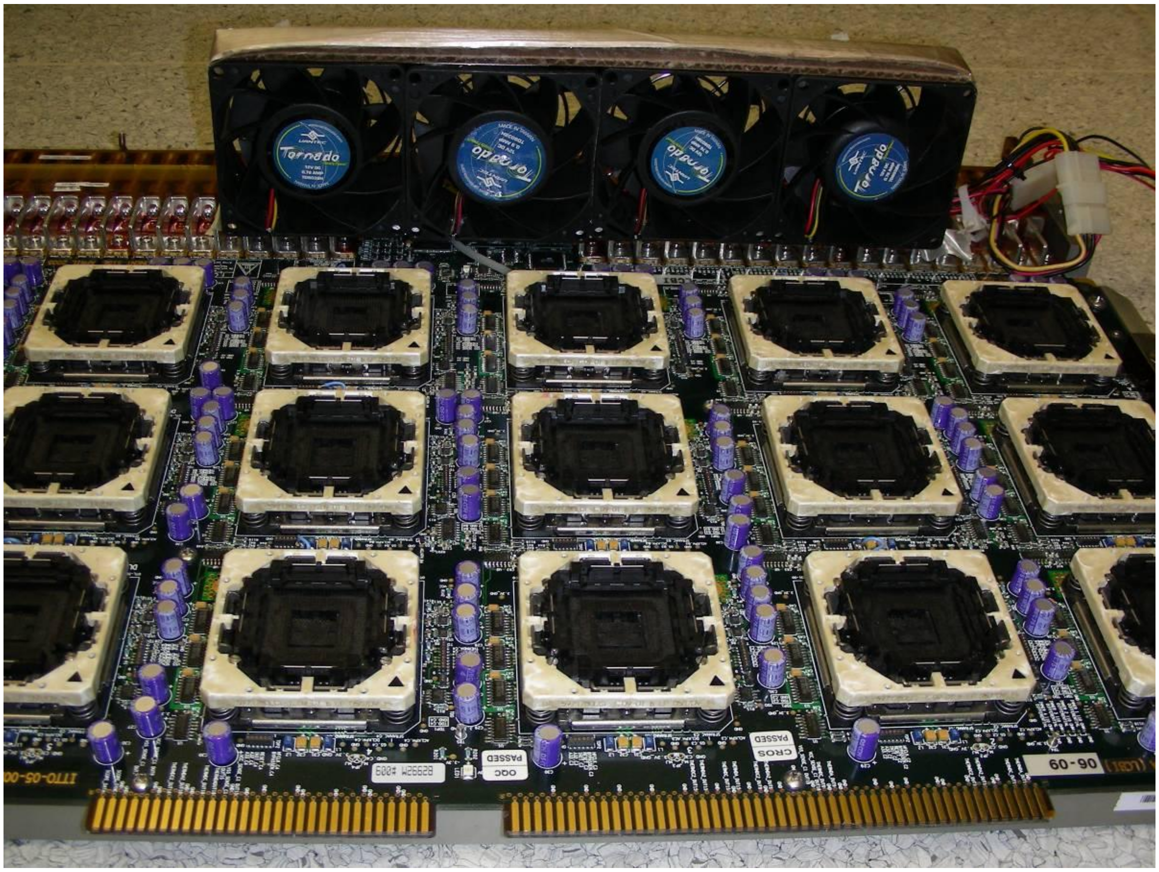

Figure 2. Burn-In Board showing 3x3 grid of sockets immediately in front of cooling fans.

The board was positioned, power bus bars upwards, in a standard spectrum-moderating Pb-Al shielding box used for Co-60 irradiation. The box was too large to fit close to the radioactive source rods within the throat of the irradiator, so it was positioned as close as possible. Incidentally, this did allow for greater uniformity of irradiation rates across the 3 x 3 grid of DUTS.

The distance from the source rods to the DUTs was further increased by the need to cool the DUTs. DUT cooling was provided by a gang of four high flow muffin fans blowing downwards across the top surface of the DUTs. A cowling was manufactured and installed so as to maintain the airflow (downwards over the DUTs) in a constant cross-section from the fans to the last row of DUTs.

Figure 3. Power Supply Bus Bars above the Cooling Fans

Power was supplied to the DUTs via a Hewlett-Packard HP6260 0-10V 100A power supply. The supply was located outside the shielded irradiation chamber and required approximately 40 feet (80 feet round trip) of 00 AWG welding cable, which had superb flexibility and provided the requisite 0.5V maximum round-trip supply cable voltage drop called out for by the supply documentation at maximum current. Both because of the bus bar and supply screw terminal sizes and numbers, and because of the cross section of the cable was three times the capacity of one lug, each end of each of the cables was ‘unbraided’ and terminated in three ring lugs. On both the burn-in board bus bars and the power supply all three lugs were connected. Remote voltage sensing for the power supply was used, with the sense voltage taken from approximately the center of the two supply rail bus bars on the burn-in board.

Power conditions were monitored so: The supply’s analog voltage and current meters were found to be very accurate, to within eyeball discernment. Current, and actual supply voltage were monitored from the front panel meter. A corroborating measure of current was derived from the voltage drop across the positive supply cable (divided by the reported resistance for that length of that gauge wire). The actual DUT voltage, as measured on the burn-in board bus bars, was also monitored.

Dose rates for the irradiations varied between 63.6 and 75.6 rad/min in order to set insertion and extraction times within normal business hours..

Verification Setup

For verification the DUTs were inserted into a bare-bones PC. A Gigabyte brand motherboard able to recognize and support the Wolfdale processor was used. A processor fan was set on top of the DUT but was not pulled down to the motherboard; it proved suitable for the short time each processor was powered. An ATX12V 2v2 power supply provided motherboard power. A PCIexpress 16x graphics card, 1 GB DDR SIM, keyboard, mouse, and monitor were also connected. The successful boot sequence from initial splash screen to the running of a standard Windows XP application program would provide the level of verification that the processor was still functional.

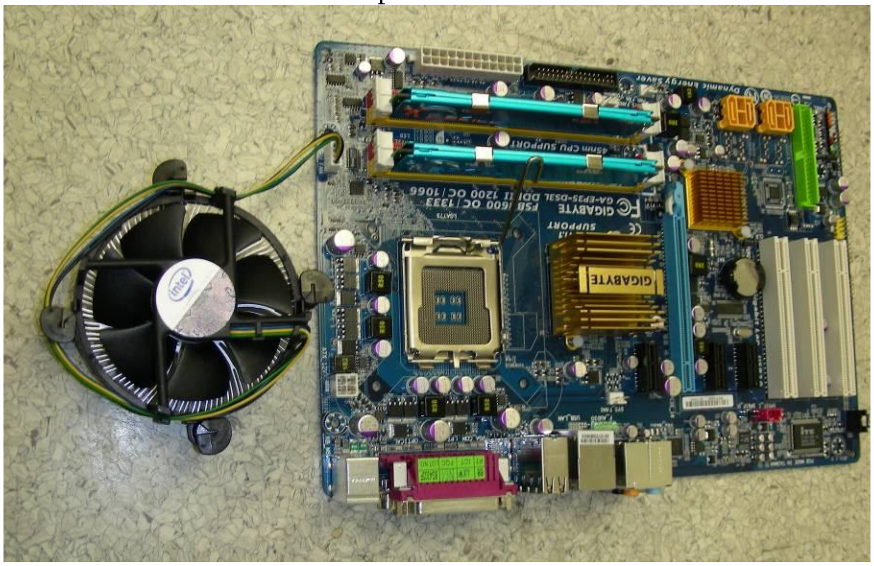

Figure 4. Verification Motherboard with Fan, Showing Empty DUT Socket Nearby.

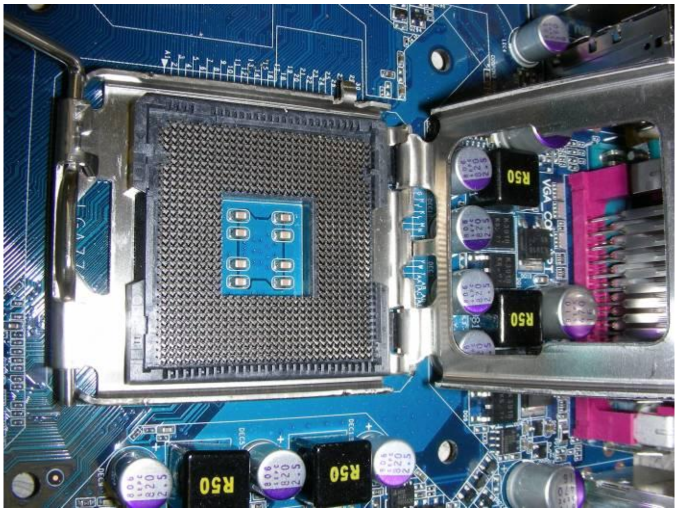

Figure 5. Closeup of Empty Motherboard Socket, Opened.

Description of Irradiation experiment

Irradiation of the units was performed from a Co60 source that delivered Gamma radiation to the DUTs according to the description in Table 1.

Table 1. Wolfdale Irradiation Schedule
(All doses in rad(Si))

Date	Incremental Dose	Total Dose, DUTs 1,2,3	Total Dose, DUTs 4,5,6	Total Dose, DUTs 7,8,9	Total Dose, DUT 10 (control)
11/21/08	0	0	0	0	0
11/24	250 K (@ 3.81 Krad(Si)/hr)	0	0	250 K	0
11/26	247 K (@ 4.3 Krad(Si)/hr)	0	247 K	497 K	0
12/01	533 K (@ 4.55 Krad(Si)/hr)	533 K	780 K	1030 K	0

Irradiation Test Sequence

With the equipment set up, and after an initial verification of all DUTs (as described in step numbers 12-15) each irradiation/verification step was conducted so, starting with all DUTs in the chip tray and all equipment powered OFF:

1. The irradiation chamber was accessed and the burn-in board was extracted from the shielding box. In an ESD-safe manner the appropriate DUTs were installed into their assigned sockets and the airflow cowling was installed. The burn-in board was reinstalled into the shielding box and the fans were turned on.
2. The power supply current limit and voltage controls were both set to zero.
3. The power supply was turned on.
4. In increments the voltage and current controls were increased until nominal voltage at the burn-in board bus bars was achieved with a small amount of headroom available in the current limiting.
5. Power supply voltage and current, positive supply cable voltage drop, and bus bar voltage were noted along with the time (i.e. “Readings were taken.”).
6. The irradiation chamber was closed and the irradiation step was begun.
7. After the prescribed dose was accumulated the irradiation step was ended and the irradiation chamber was accessed.
8. Readings were taken.
9. The power supply voltage and current settings were both set to zero.
10. The fan supply was turned off.
11. In an ESD-safe manner the DUTs were extracted and inserted into the chip tray and carried to the verification setup.
12. In an ESD-safe manner one of the group (of just-irradiated DUTs plus the control) was inserted into the motherboard socket. The processor fan was set firmly onto the DUT.

13. The PC power supply was turned ON and the motherboard power switch terminals were momentarily closed to turn the computer ON.
14. The computer display was observed to verify that the expected sequence of indications verifying proper processor operation occurred (e.g. the operating system would boot and then the selected application program would load and run. This would complete the verification.
15. The PC power supply was turned OFF, the fan removed, and in an ESD-safe manner the DUT was returned to the chip tray.
16. After all recently-irradiated DUTs plus the control were verified the next irradiation step was executed.

Results

At every test all DUTs were operational with no detected differences. Burn-In Board supply current never varied throughout the test.

The DUTs plus the control were returned to Intel for a repeat of the detailed parametric testing performed before delivering the DUTs for testing. After clarifying one possible out-of-bounds result on one DUT as actually showing no change, the result of no observed change of any parameter on any DUT, with the tolerance of the test equipment used, was concluded. Table 2 shows a summary of these exciting results.

Table 2 Parametric Test Results

(WTT = Within Tester Tolerance)

DUTID	TID (Krad(Si))	Vmax Degradation	Vmin Degradation	Performance Degradation	Power Degradation
1	500	WTT	WTT	WTT	WTT
2	500	WTT	WTT	WTT	WTT
3	500	WTT	WTT	WTT	WTT
4	750	WTT	WTT	WTT	WTT
5	750	WTT	WTT	WTT	WTT
6	750	WTT	WTT	WTT	WTT
7	1000	WTT	WTT	WTT	WTT
8	1000	WTT	WTT	WTT	WTT
9	1000	WTT	WTT	WTT	WTT
10 (Control)	0	WTT	WTT	WTT	WTT

Discussion of results

A very limited test was possible on these complex devices. Nonetheless, because of their very large integration factor and complexity, a result of "operational" leads to a reasonable presumption that no portion of the DUT circuitry was degraded to the point of being unfunctional.

That the supply current did not vary over the duration of the testing further leads to the conclusion that there was no degredation of the DUTs.

The report from Intel of the parametrics of the DUTs fully corroborates these conclusions.

Conclusion for Total Ionizing Dose (TID) Experiment

No detectable damage or degradation has been identified on Wolfdale microprocessor units upon Gamma irradiation from a Co60 source up to 1.036 Krads(Si) levels.