SAND2008-0395P

Permafrost Digital Controller: A MESA Success Story

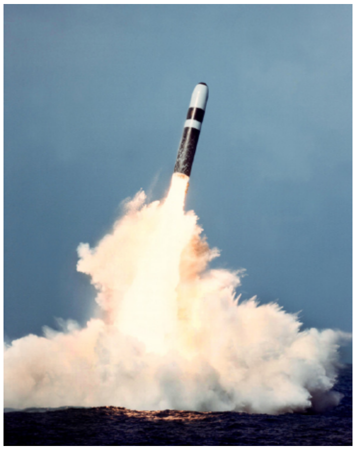

Fig. 1 Submarine launched Trident W76-1

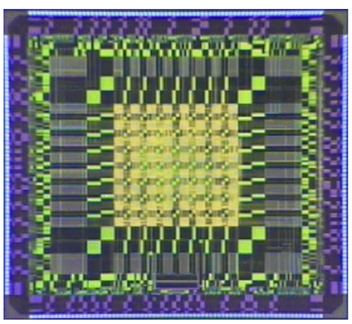

Fig. 2: Permafrost chip

Sandia's Microsystem and Engineering Sciences Applications (MESA) program delivers custom chip on time and at cost

Pioneering a New Approach to Warhead Life Extensions

The submarine-launched Trident W76-1 nuclear warhead (Fig. 1) is a crucial element in our nation's nuclear deterrence. Planning for the refurbishment of the W76 warhead, which entered active service in 1978, began in April 1997. The aggressive W76-1 refurbishment was given a goal of one quarter the cost of the previous submarine warhead. Meeting this demanding goal motivated a new warhead design philosophy.

A New Design Philosophy

To bring costs down, Sandia designers used a two-pronged approach. They relied on extensive use of low-cost Commercial, Off-the-Shelf (COTS) components for the least complicated tasks (e.g., diodes, transistors), and they integrated the more complex digital logic circuitry into a single Application-Specific Integrated Circuit—a chip called "Permafrost" (Fig. 2) because all the requirements were "frozen" to enable the design to go forward. This chip had to meet demanding requirements for survivability against nuclear countermeasures, while assuring completely predictable, trusted operational behavior.

Developing a New, Radiation-Hardened Technology Required Strong Scientific Support

Commercial microelectronics continually shrink to smaller feature sizes according to an empirical rule known as "Moore's law", where the number of transistors that can be inexpensively placed on an integrated circuit approximately doubles every two years. Knowing that the first production unit would be required in 2006, Sandia scientists began development of a radiation-hardened integrated-circuit technology based on transistors with minimum feature sizes of 0.35 micrometers (approximately one three-hundredth of the width of a human hair).

Computer Simulations Motivate Invention of the BUSFET

Early modeling and simulation indicated that the radiation-hardening techniques which succeeded for 0.5 micrometer technology would not be sufficient for these smaller transistors. The initial computer simulations alone saved over $1.5M in development costs and nine months of schedule. Armed with the knowledge gained from scientific research and computer simulations, Sandia developed a new transistor type, the Body-Under-Source, Field-Effect Transistor, or BUSFET, for which Sandia received a DOE Weapon Award of Excellence.

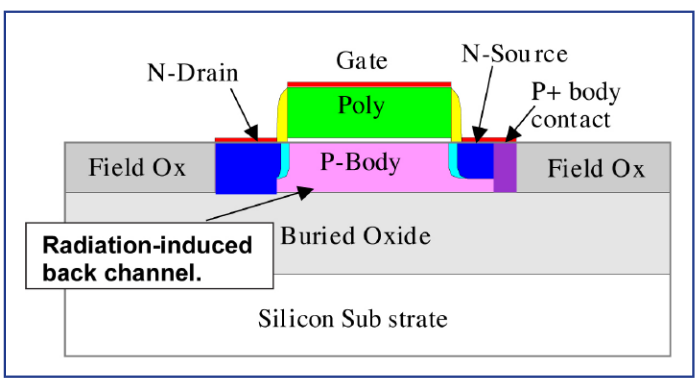

Fig. 3: Schematic of BUSFET device

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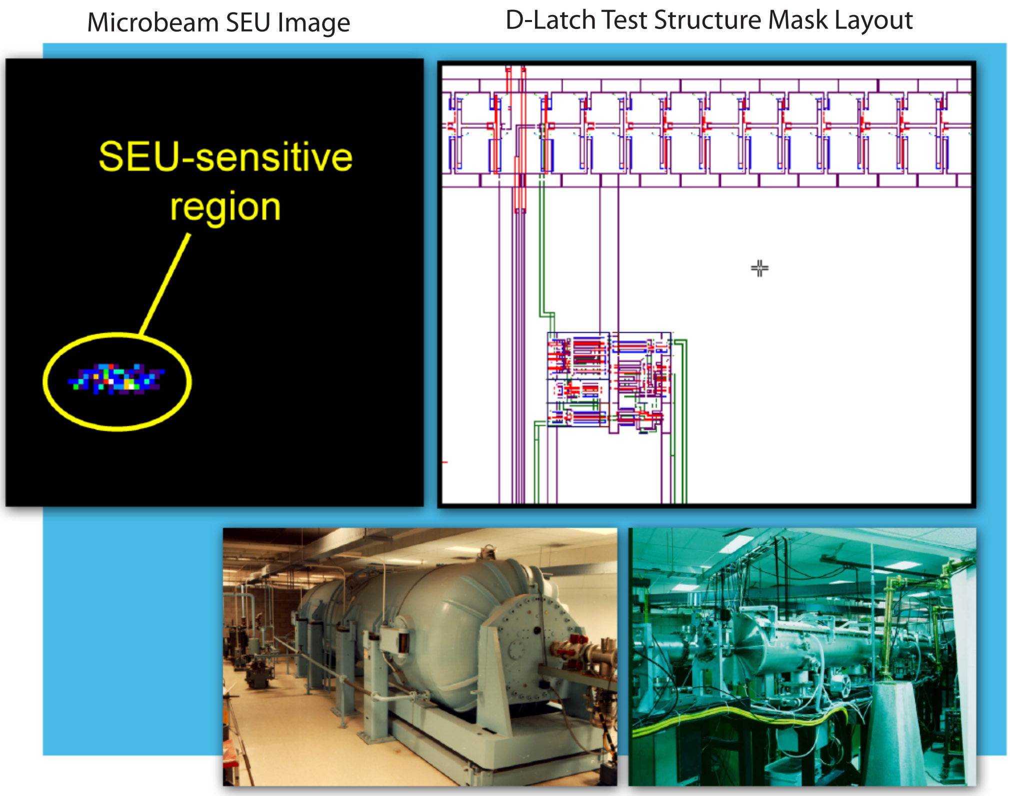

Fig. 4: A focused ion microbeam located the Single Upset Event (SEU) in the BUSFET. By registering the microbeam SEU image to the design mask layout, the sensitive circuit node was located in certain CMOS7 latches in the standard cell library.

Ion-Beam Microscope Identifies Vulnerability to Enable Hardened Circuits

The BUSFET is characterized by asymmetric transistor sources and drains, which greatly enhances radiation survivability but complicates laying out circuit functions. While the individual transistors are resistant to incoming radiation, initial development was challenged by an unexpected radiation sensitivity of one particular combination of transistors. Sandia's focused ion-microbeam, with a spot size of one micrometer, was scanned over the circuit while observing the circuit function in real time (Fig. 4). This lead to an identification of the vulnerable node and easy remediation of the circuit design. With this key advance, the technology was ready and the design was completed.

No Alternative to MESA

The U.S. Navy convened a source-selection board to determine which supplier should fabricate the demanding Permafrost controller. When no private-sector supplier was willing to meet the demanding performance and survivability requirements demanded for this strategic system, Sandia stepped up to the challenge and accepted the fabrication responsibility.

MESA Investment Enables On-Time, On-Budget Deliveries

The MESA program recently re-tooled over one-third of the semiconductor processing equipment in Sandia's silicon fabrication facility. The new equipment more than doubled the number of working chips on each wafer, enabling Sandia to meet the aggressive cost, performance, and schedule requirements of this key warhead refurbishment.

A Real Success

To date, the Permafrost controller has passed every demanding radiation test and MESA has met every scheduled delivery on time and at the negotiated cost. The Permafrost Controller and the technology are being continually improved to reduce cost and design time while remaining an established element in the design philosophy for the future stockpile.

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NNSA National Nuclear Security Administration

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