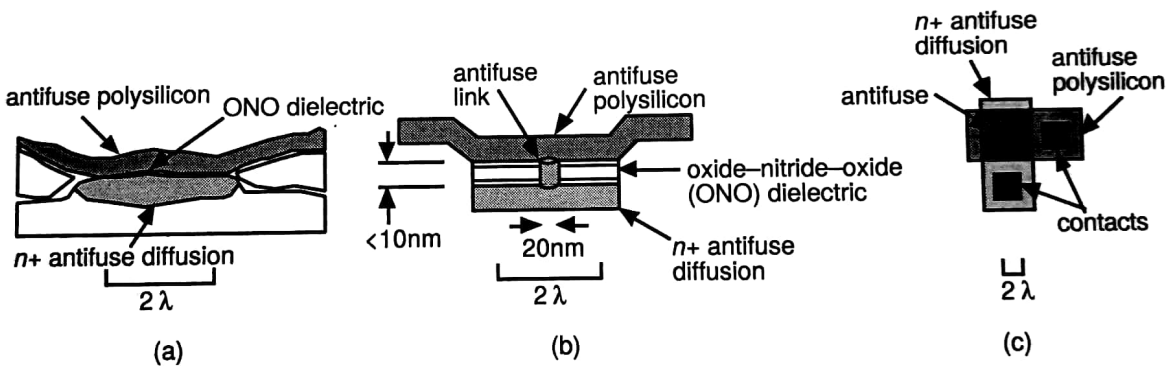
PROGRAMMABLE ASICs

4

Key concepts: programmable logic devices (PLDs) • field-programmable gate arrays (FPGAs) • programming technology • basic logic cells • I/O logic cells • programmable interconnect • software to design and program the FPGA

4.1 The Antifuse

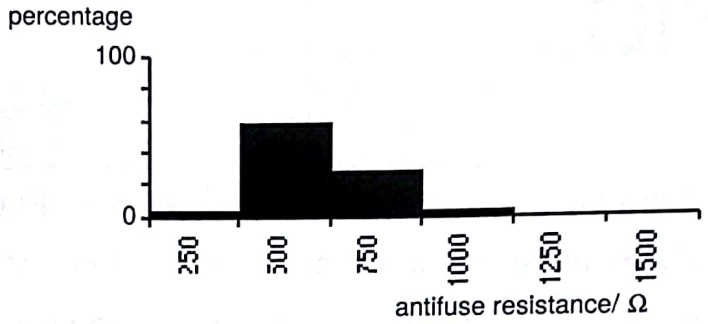


Actel antifuse

antifuse • programming current (about 5mA) • (PLICE') • oxide–nitride–oxide (ONO) dielectric • Activator • in-system programming (ISP) • gang programmers • one-time programmable (OTP) FPGAs

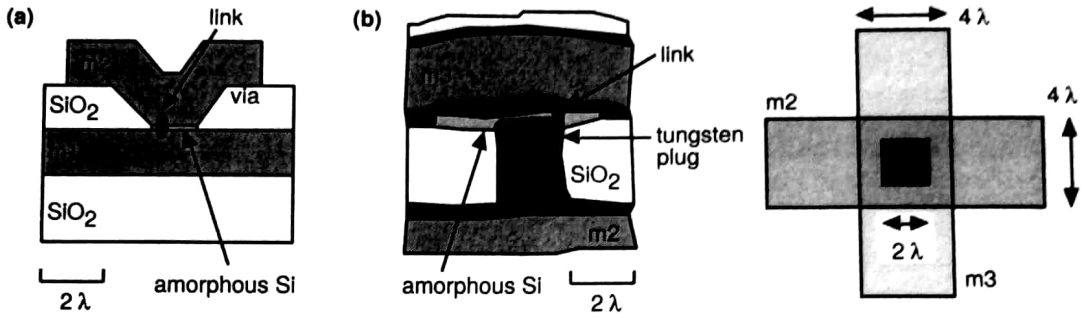
Number of antifuses on Actel FPGAs

Device	Antifuses
A1010	112,000
A1020	186,000
A1225	250,000
A1240	400,000
A1280	750,000



The resistance of blown Actel antifuses

4.1.1 Metal–Metal Antifuse



Metal–metal antifuse

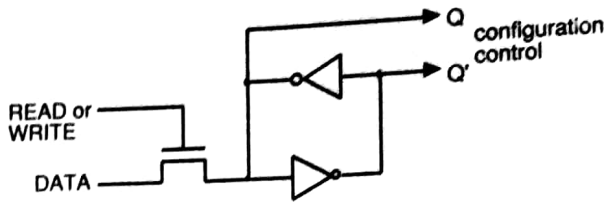
QuickLogic metal–metal antifuse (ViaLink') • alloy of tungsten, titanium, and silicon • bulk resistance of about 500mΩcm

Resistance values for the QuickLogic metal–metal antifuse

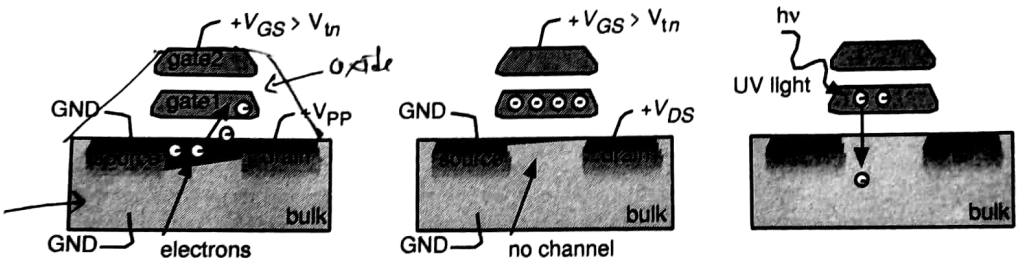
4.2 Static RAM

Xilinx SRAM (static RAM) configuration cell

- use in reconfigurable hardware
- use of programmable read-only memory or PROM to hold configuration



4.3 EPROM and EEPROM Technology



An EPROM transistor

(a) With a high (>12V) programming voltage, V_{PP}, applied to the drain, electrons gain enough energy to "jump" onto the floating gate (gate1)

(b) Electrons stuck on gate1 raise the threshold voltage so that the transistor is always off for normal operating voltages

(c) UV light provides enough energy for the electrons stuck on gate1 to "jump" back to the bulk, allowing the transistor to operate normally

Facts and keywords: Altera MAX 5000 EPLDs and Xilinx EPLDs both use UV-erasable electrically programmable read-only memory (EPROM) • hot-electron injection or avalanche injection • floating-gate avalanche MOS (FAMOS)

Types of Programming for Antifuse Devices

Depending on the number of devices you wish to program and the type of device, you can choose from the following programming methods.

- Device programmers
  - Single-site programmers
  - Multi-site programmers, batch programmers or gang programmers
- Volume programming services
  - SoC Products Group in-house programming (IHP)
  - Programming centers

Device Programmers

Device programmers are used to program a device before it is mounted on the system board. It can either be programmed before being soldered (usually done in production), or programmed before putting it into a socket (used for prototyping).

The advantage of using device programmers is that no programming hardware is required on your system board. Therefore, no additional components or board space are required.

If you intend to program devices frequently with different programs, or if you program relatively small volumes of devices, buying a single-site device programmer is the simplest solution. For some military or space designs, you may also want to use programming onsite to maintain control of the devices at all times.

Adapter modules are purchased with the programmers to support the FPGA packages you intend to use. When you receive the FPGA, place it in the adapter module and run the programming software from a PC. SoC Products Group supplies the programming software for all the SoC Products Group programmers. The software enables you to select your device, programming files, program, and verify the device.

- Single-Site Programmers

  A single-site programmer programs one device at a time. SoC Products Group offers Silicon Sculptor II and Silicon Sculptor 3 as single-site programmers.
  - Advantages: Lower cost than multi-site programmers. No additional overhead for programming on the system board. Allows local control of programming and data files for maximum security. Allows on-demand programming onsite.
  - Limitations: Only programs one device at a time.
- Multi-Site Programmers

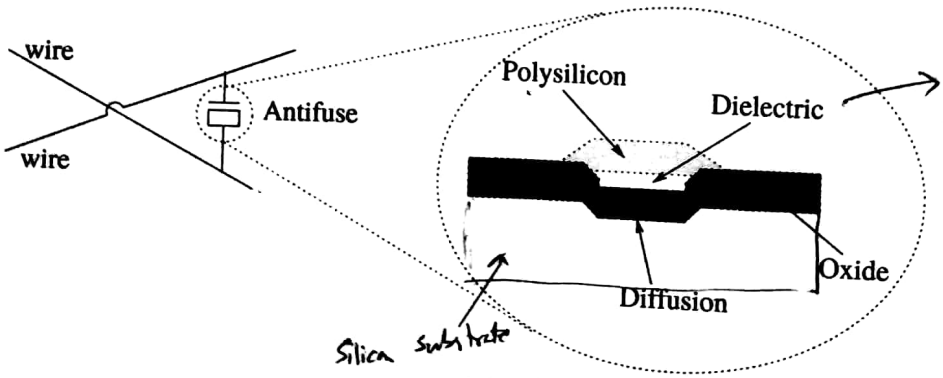
  Often referred to as batch or gang programmers, multi-site programmers can program multiple devices at the same time using the same programming file. This is often used for large volume programming and by programming houses. The sites often have independent processors and memory enabling the sites to operate concurrently, meaning each site may start programming the same file independently enabling the operator to change one device while the other sites continue programming, which increases throughput. You need to buy multiple adapter modules for the same package when using a multi-site programmer. Silicon Sculptor II and 3 programmers can be cascaded to program multiple devices in a chain. Multi-site programmers can also be purchased from BP Microsystems.
  - Advantages: Provides the capability of programming multiple devices at the same time. No additional overhead for programming on the system board. Allows local control of programming and data files for maximum security.
  - Limitations: More expensive than a single-site programmer.

Programming Technologies

- Programming technologies may be permanent or non-permanent.
- For commerical FPGAs, the main switch technologies are *antifuses* (e.g. Actel) and *Static RAM cells* (e.g. Xilinx).
- For commerical CPLDs (e.g. Altera MAX), the main switch technologies are *Erasable Programmable ROM (EPROM) transistors* and *Electrically Erasable PROM (EEPROM) transistors*.

Antifuse Programming Technology

- An *antifuse* is the opposite of a regular fuse. It is an open path until a programming current is forced through it by applying a high programming voltage across it.
- Programming current controls the antifuse resistance (typically for 5mA it is 500 ohms) — Reduce resistance by increasing current.
- Advantage: small (allow denser switch population).
- Disadvantage: only one-time programmable.



Actel's PLICE antifuse structure. (Programmable low-impedance circuit element)

Metal-Metal Antifuse

- Metal-metal antifuse is direct to metal-the wiring layers
- Resistance below 50 Ω
- 10V is required to fuse

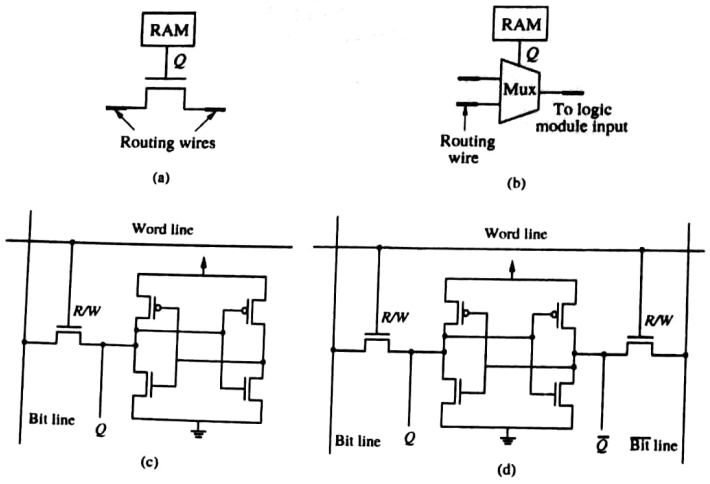
QuickLogic

Link (Amorphous Si)

- Non-crystalline form of silicon
- Thin film
- Photovoltaic material

Static RAM (SRAM) Programming Technology

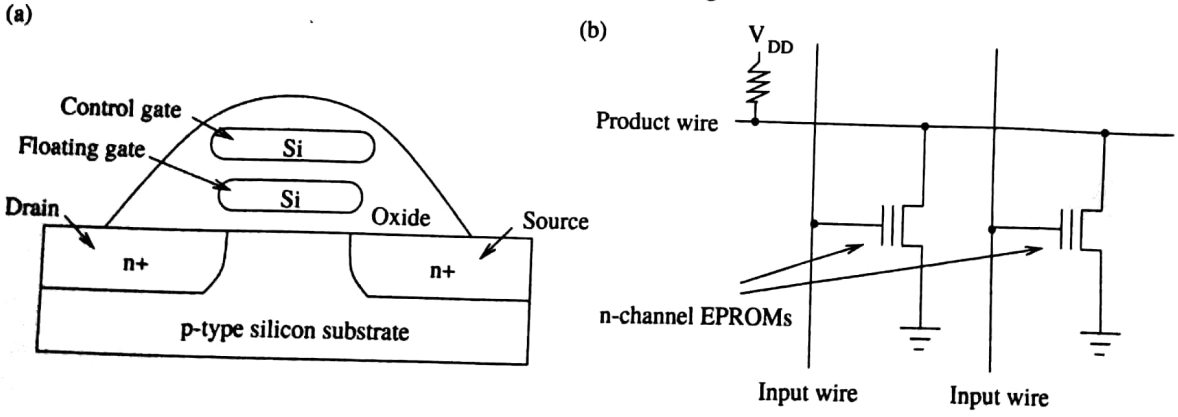
- Use SRAM cells to control pass transistors or multiplexers by the bit-content in the SRAM cells.
- Advantage: reprogrammable; Disadvantage: occupy more space.



(a)(b) A pass-transistor switch/multiplexer switch controlled by a RAM cell. (c)(d) SRAM cells implemented using five/six transistors.

EPROM Programming Technology

- Use an EPROM transistor as a programmable switch.
- A n-channel EPROM transistor is programmed by applying higher-than-operation voltages to the drain and the control gate.
- Become an open path when programmed because electrons trapped on the floating gate raise the threshold voltage of the n-channel EPROM transistor above V_{DD}.
- Erasable by exposing the floating gate to UV light.



(a) A n-channel EPROM transistor. (b) A section of an EPROM-based device.

Programming Technologies Summary

Programming technology	SRAM	Poly-Diffusion antifuse	Metal-Metal antifuse	EPROM	EEPROM
Manufacturing Complexity	+	−	−	−	−−
Reprogrammable?	Yes In circuit	No	No	Yes Out of circuit	Yes In circuit
Physical size	Large (12X)	Small (2X)	Small (1X)	Small	Small
ON resistance (Ω)	600–800	100–500	30–60	1-4K	1-4K
OFF capacitance (*fF*)	10–50	3–5	1	10–50	10–50
Power consumption	++	+	+	−	−
Volatile?	Yes	No	No	No	No

+ desirable; − undesirable

Logic Cell Architecture

- Both FPGA and CPLD are made up of a set of basic logic cells.
- A basic logic cell has a fixed number of inputs and outputs, and can implement a certain set of functions.
- Logic cells used in FPGAs:
  - multiplexer based (e.g. Actel)
  - lookup-table based (e.g. Xilinx, Lucent)
- Logic cells used in CPLDs:
  - programmable array logic (PAL) based (e.g. Altera MAX, Xilinx XC9500).