Floating Gate Transistor

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ECE 3080 Presentation

Floating Gate Transistors

- **Structure**
- **Function analysis**
- **“Readable” and “Writable”**
- **Use in nonvolatile memory**

Introduction

- **Works the same way that MOSFET works**
- **Has extra “floating gate”**
- **Stores charge on the floating gate**
- **EPROM and EEPROM**

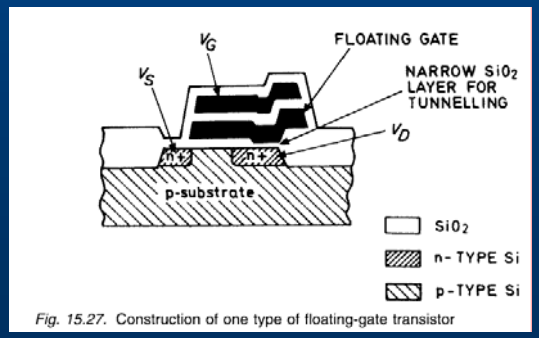
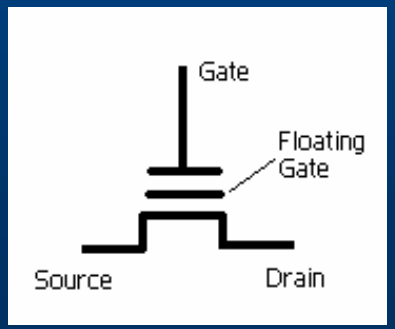


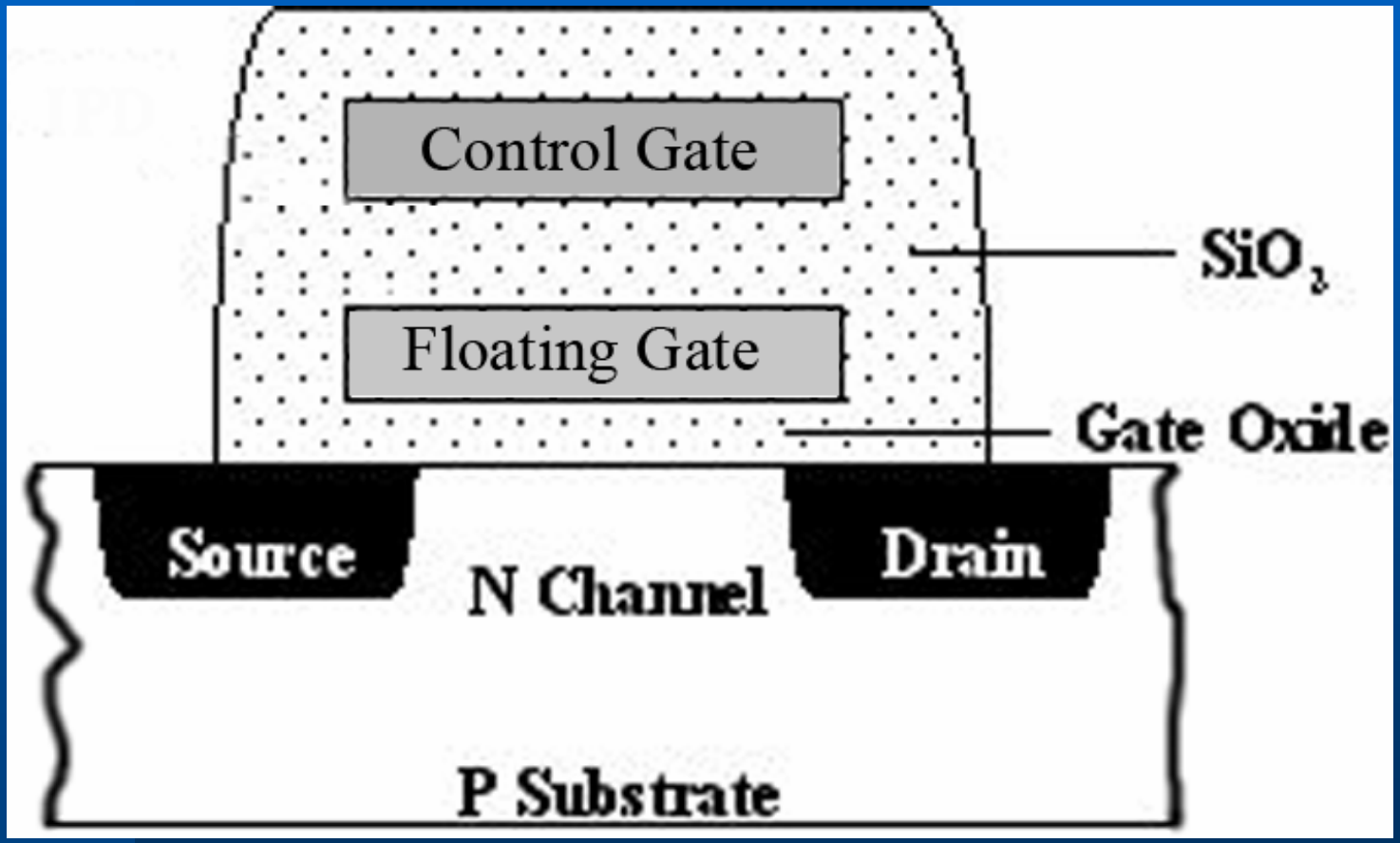
Fig. 15.27. Construction of one type of floating-gate transistor



History

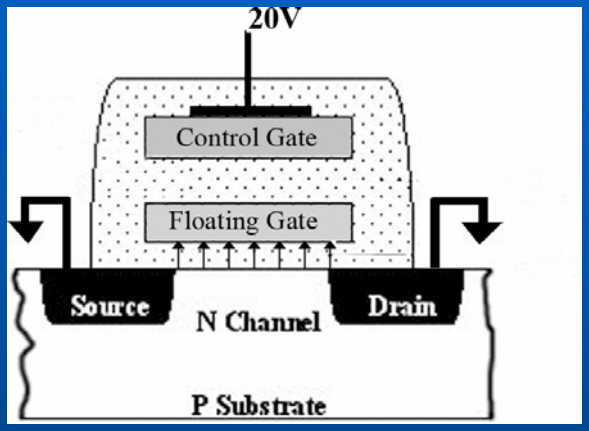
- **Founded by Kahng and Sze (Bell Labs) 1967**
- **EPROM invented by Don Fohman 1971**
- **EEPROM invented by George Perlegos (Intel) 1983**
- **Beginning to move out of memory uses toward neuromorphic systems**

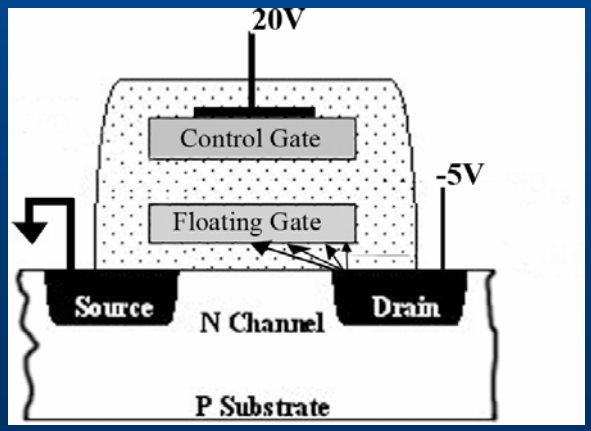
FGMOS Analysis



FGMOS: Programming

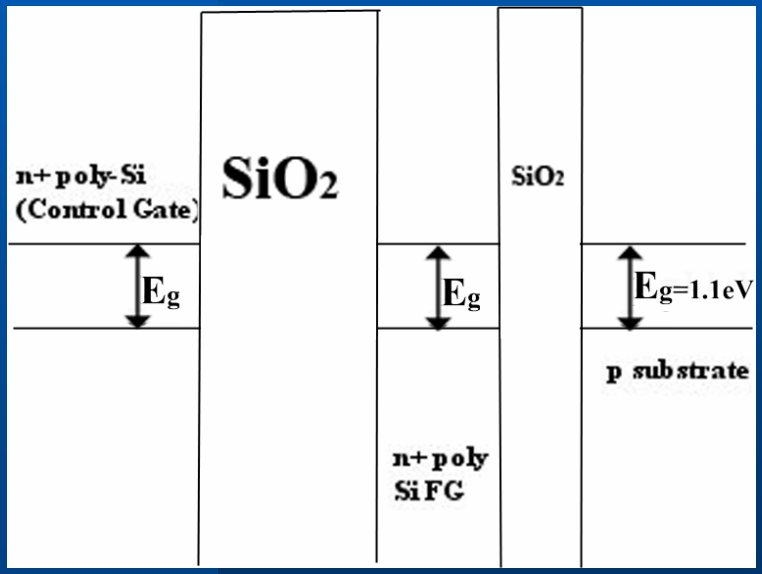
- ***Fowler-Nordheim (FN) Tunneling***
  - **Silicon Dioxide layer act as a boundary**
  - **Large voltage is applied to the Control Gate**
  - **Voltage create a high electric field**
  - **Electrons tunnel through thin SiO_2 barrier**
  - **Thin: 5-12nm Thick: 25-45nm**



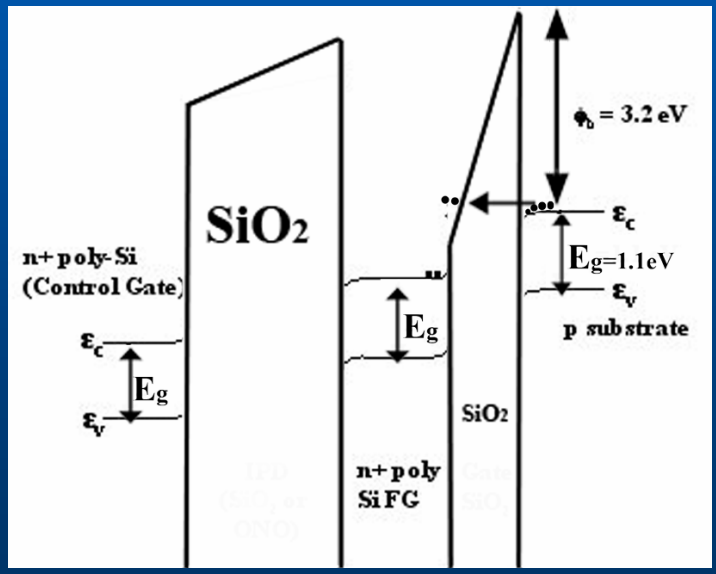


FGMOS: Programming

Normal Band Diagram



***Fowler-Nordheim (FN) Tunneling* Band Diagram**



FGMOS: Programming

$$J = \alpha \mathrm{E}^2 \cdot \exp(-\frac{\beta}{\mathrm{E}})$$

where

$$\alpha = \frac{q^3}{8\pi \cdot \phi_b} \cdot \frac{m}{m^*}$$

$$\beta = 4\sqrt{2m^*}\,\frac{\phi_b^{\frac{3}{2}}}{3\hbar q}$$

$\hbar$ = Planck's Constant

ϕ_b = Energy Barrier at the injecting surface (3.2 eV for Si - SiO2)

q = Charge of electron

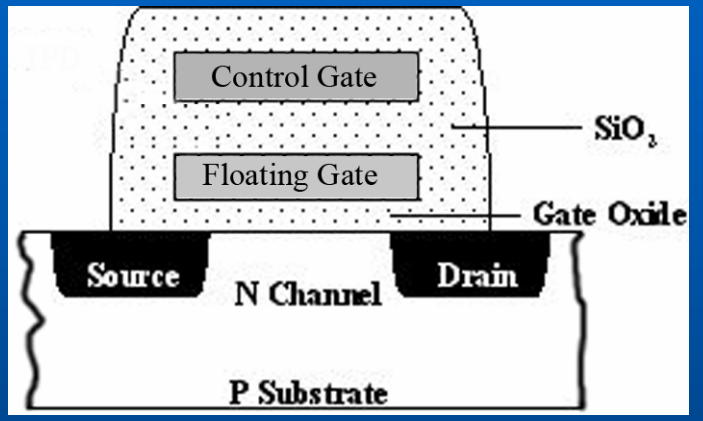
m = Mass of free electron

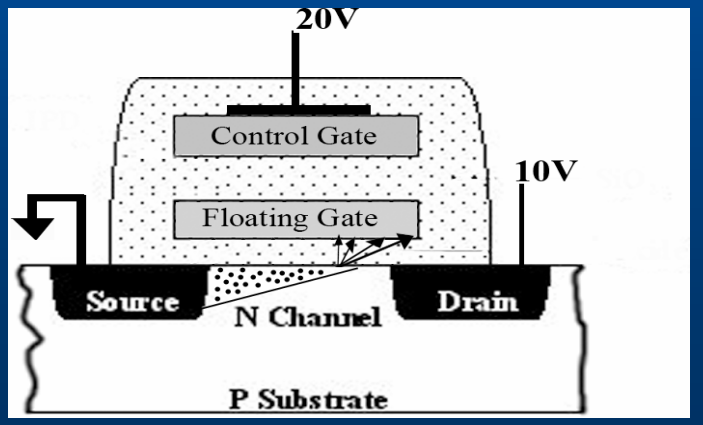
m^* = Effective Mass of an electron

E = Electric field at the injecting surface

FGMOS: Programming

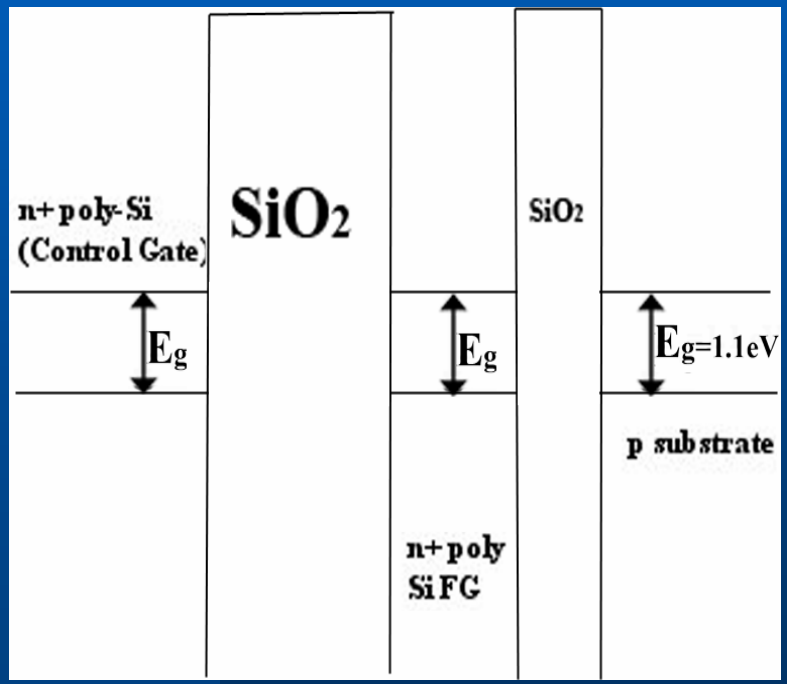
- **Hot-Carrier Injection (HCI)**
  - **Hot Electron injection for N-Type and Hot Hole injection for P-Type (longer for Holes)**
  - **Drain is biased causing electric field**
  - **Control gate biased to create second electric field**
  - **Electrons or holes gain enough energy to exceed energy barrier**



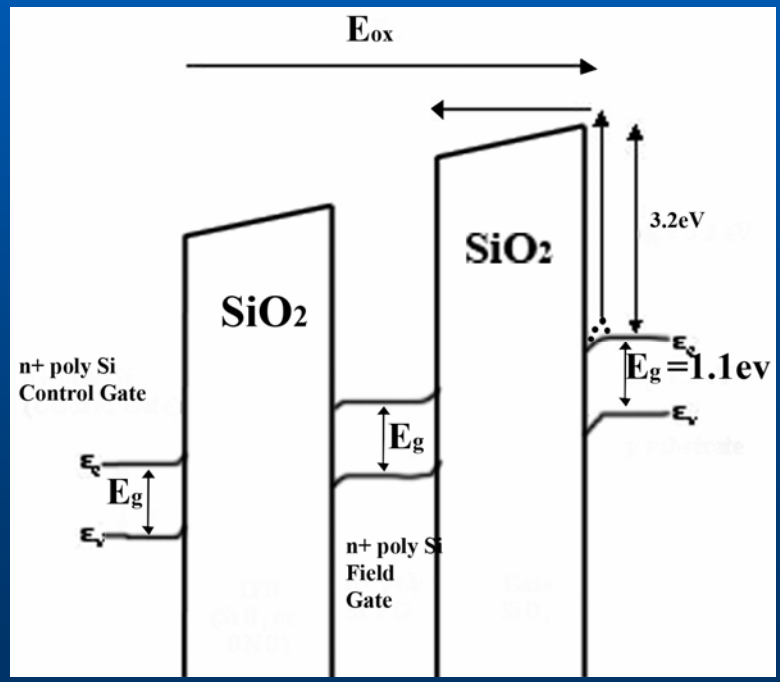


FGMOS: Programming

Normal Band Diagram

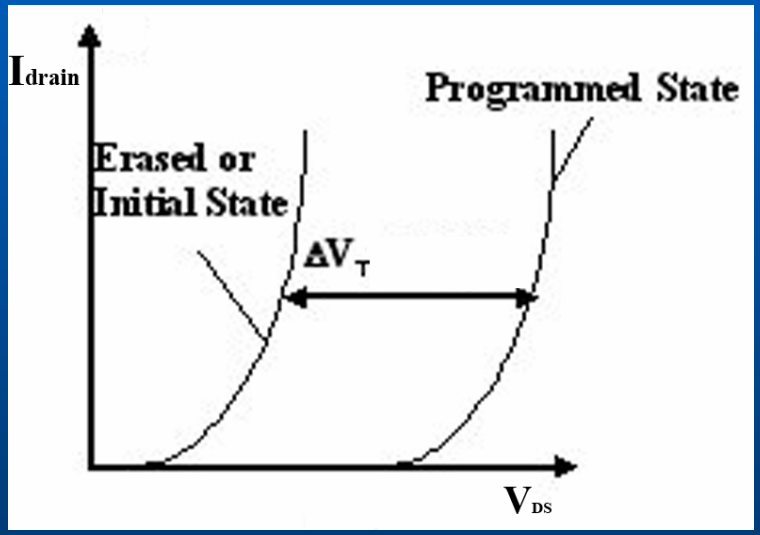


Hot-Electron Injection Band Diagram



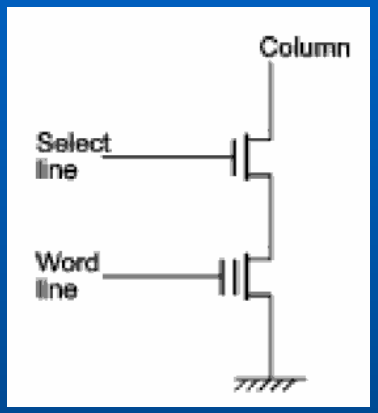
FGMOS: Reading

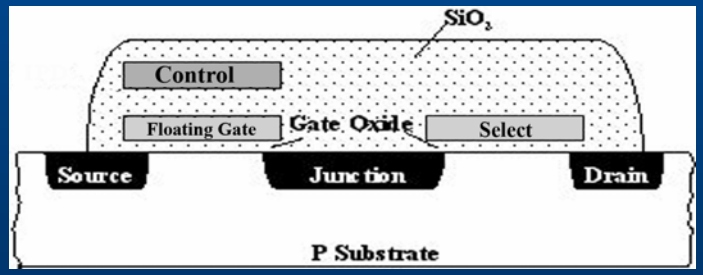
- **Programming**
  - **Setting the FGMOS to “0”**
- **Erasing**
  - **Setting the FGMOS to “1”**



FGMOS: Reading

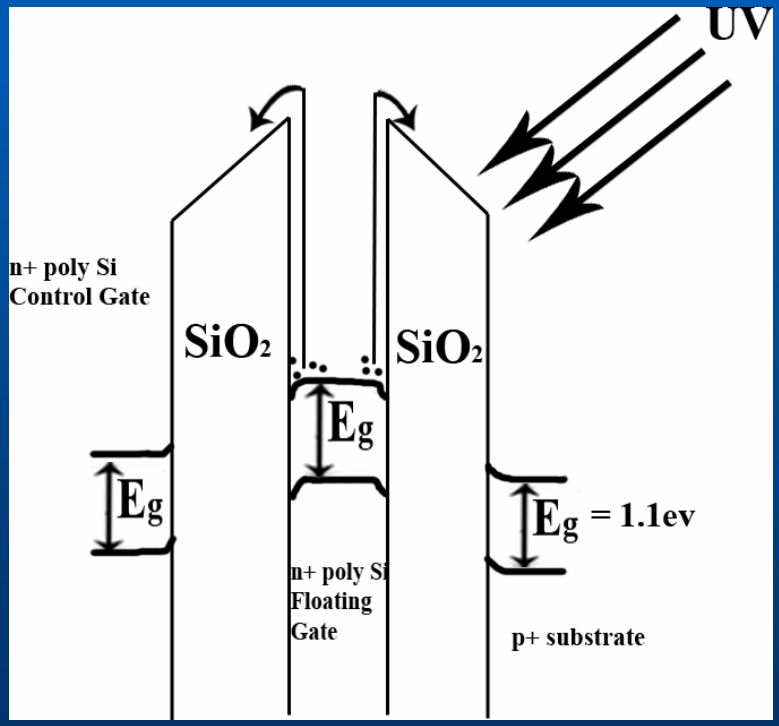
- Select line is brought high (3.5 V)
- Bit line is brought high (3.5 V)
- Current pulse is sent through column
- Cell sensor detects current pulse



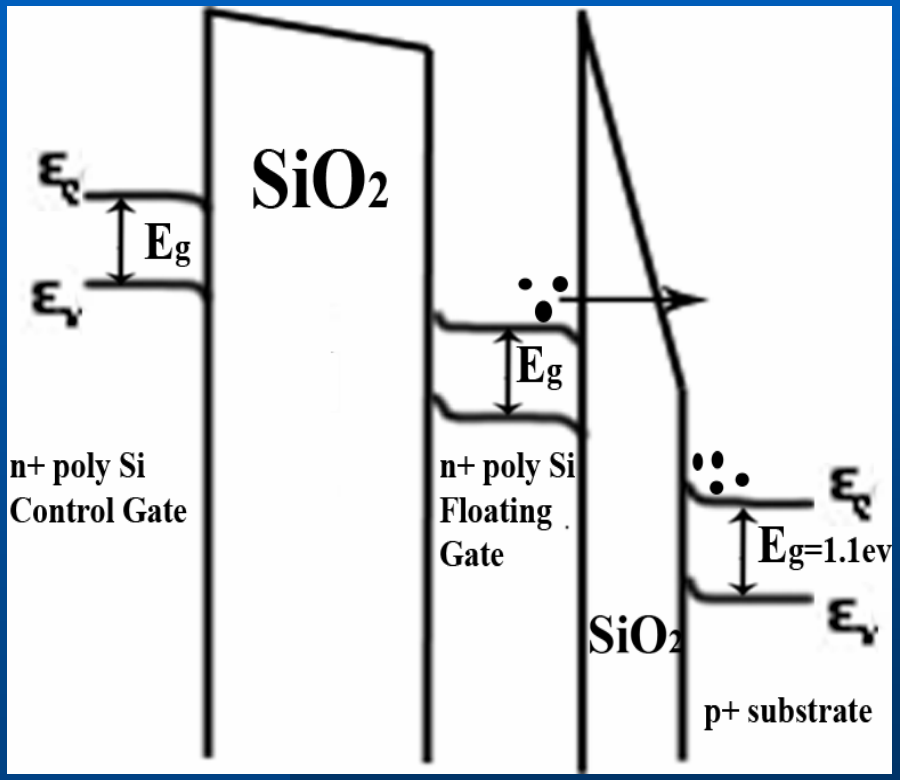


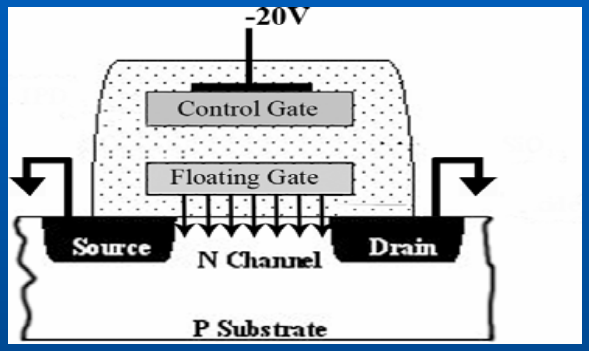
FGMOS: Erasing

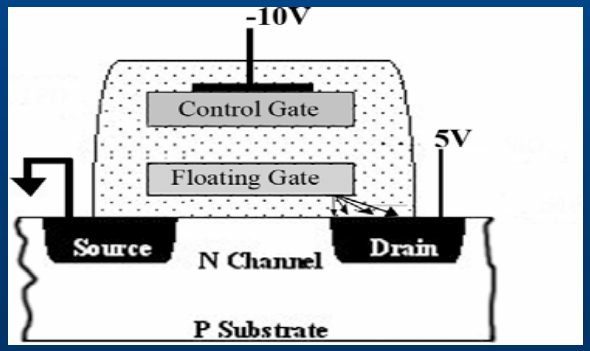
- **Erasable Programmable Read Only Memory (EPROM)**
  - **Can be individually address and programmed, not erased**
  - **Use another tool to erase**
  - **Excites electrons over the insulating barriers**
  - **UV light at 253.7 nm wavelength most efficient**
    - **3 weeks sunlight**
    - **1 year fluorescent light**
    - **4.5 minutes Germicidal Lightbulb**



EEPROM: Erasing

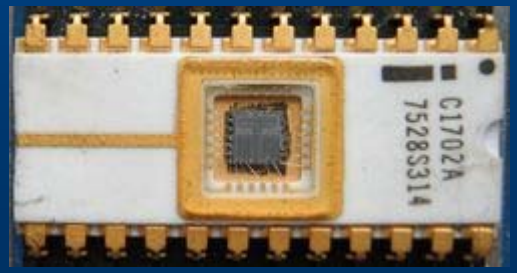






EPROM/EEPROM Devices

- **EPROM**
  - **Gameboy, Sega Genisis, NES**
  - **Microcontroller**
  - **10 to 20 year retention**



- **EEPROM**
  - **Flash Drives**
  - **SSD Hard Disks**
  - **SPI, I2C, 1-Wire**
  - **10 years or more retention**

Questions?

- [1] *Stanley William Amose and Mike James, "Principle of Transistor Circuits: Intro to the Design of Amplifier" pp323-325*
- [2] Jitu J. Makwana and Dr. Dieter K. Schroder, "A Nonvolatile Memory Overview"
  - http://aplawrence.com/Makwana/nonvolmem.html
- [3] Paul Hasler, Bradley Minch and Chris Diorio, "Floating-Gate Devices: They Are Not Just For Digital Memories Anymore"
- [4] Edgar Sanchez-Sinencio, "Floating Gate Techniques and Applications", http://amesp02.tamu.edu/~sanchez/607-2005-Floating%20Gate%20Circuits.pdf
- [5] "EPROM." *Wikipedia, The Free Encyclopedia*. 30 Mar 2008, 02:28 UTC. Wikimedia Foundation, Inc. 14 Apr 2008 <http://en.wikipedia.org/w/index.php?title=EPROM&oldid=201956136>.
- [6] "EEPROM." *Wikipedia, The Free Encyclopedia*. 11 Apr 2008, 19:08 UTC. Wikimedia Foundation, Inc. 14 Apr 2008 <http://en.wikipedia.org/w/index.php?title=EEPROM&oldid=204977559>.
- [7] "Floating-gate transistor." *Wikipedia, The Free Encyclopedia*. 10 Mar 2008, 07:06 UTC. Wikimedia Foundation, Inc. 14 Apr 2008 <http://en.wikipedia.org/w/index.php?title=Floating-gate_transistor&oldid=197181021>.