Session 302-C: Creating the Foundation of the Flash Storage Memory Industry: A Conversation with Eli Harari

Brian A. Berg, FMS Technical Chair
In Conversation with Eli Harari

Eli Harari Interview

- JFK Speech (1961) Moon Landing (1969)

Eli Harari Interview

- Princeton University (1969-73)
- Ph.D.: 1973

PRINCETON UNIVERSITY

CHARGE TRAPPING EFFECTS IN THIN FILMS

OF Al_2O_3 AND SiO_2

Eliyahou Harari

Eli Harari Interview

- Hughes Microelectronics, Newport Beach, CA (1973-79)

HUGHES
SEMICONDUCTOR DIVISION
Industrial Electronics Group

First F-N Tunneling Floating gate EEPROM

United States Patent [19] [11] 4,115,914
Harari [45] Sep. 26, 1978

[54] **ELECTRICALLY ERASABLE NON-VOLATILE SEMICONDUCTOR MEMORY**

[75] Inventor: **Eliyahou Harari**, Irvine, Calif.

[73] Assignee: **Hughes Aircraft Company**, Culver City, Calif.

[21] Appl. No.: **770,346**

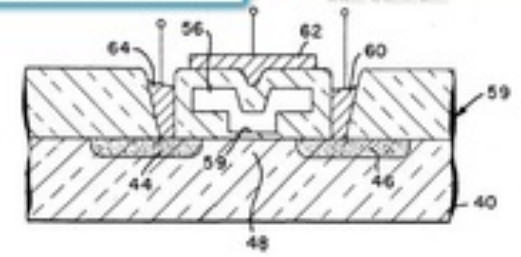
[22] Filed: **Feb. 22, 1977**

Related U.S. Application Data

[62] Division of Ser. No. 671,183, Mar. 26, 1976.

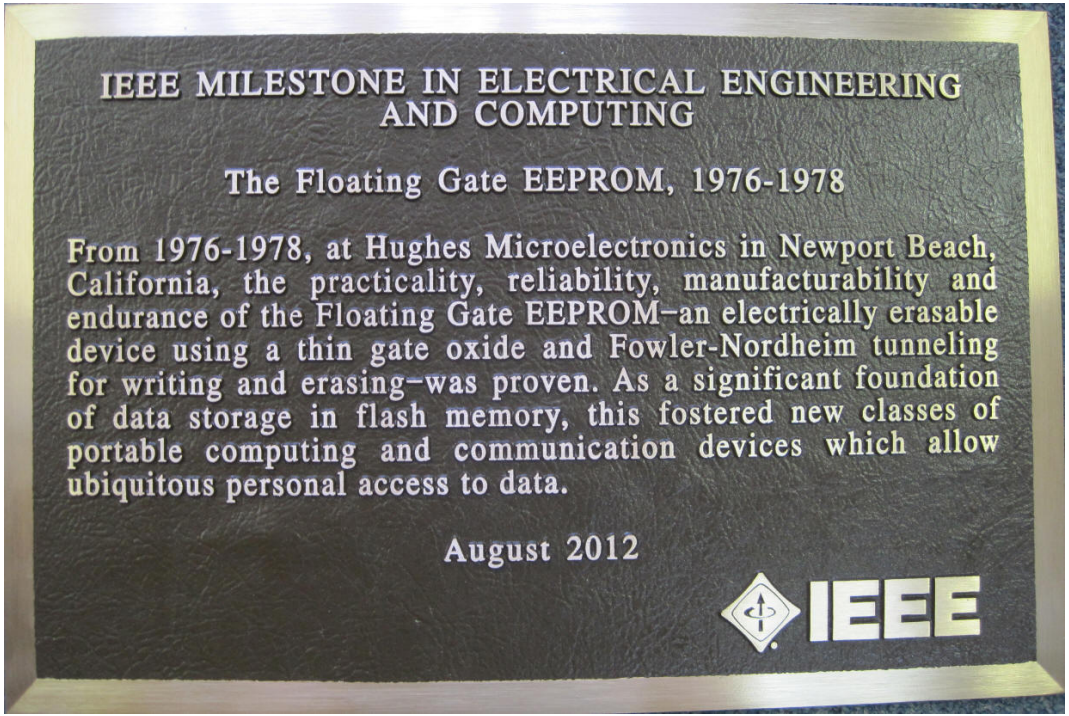
A predetermined section of this insulating layer is relatively thin to permit this section of the floating gate to be relatively close to a corresponding predetermined section of the transistor, thus facilitating the transfer of charges between the transistor substrate and the gate.

Erasing is achieved by removing the charges from the floating gate by reverse tunneling through the relatively thinner insulator region.



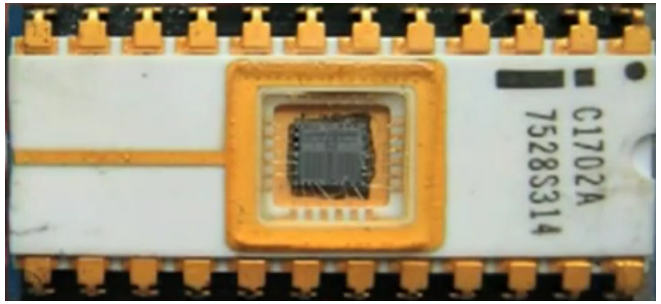
Eli Harari Interview

- IEEE Milestone dedicated in 2012 for this 1976-1978 EEPROM work, and how it led to “System-Flash”
- Harari also received the 2012 FMS Lifetime Achievement Award



Eli Harari Interview

- Dov Frohman invented EPROM at Intel (1971)

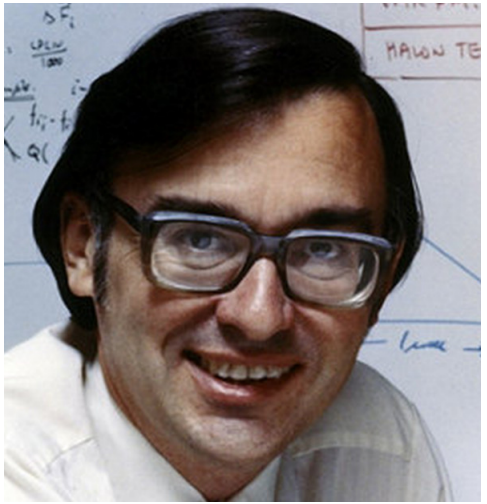


- Dov interviewed Eli in 1979 for a job at Intel

Eli Harari Interview

- Worked at Intel (1979-81)
- Eli proposed an SSD to Intel President Andy Grove

"10x" Story from Ted Hoff



Eli Harari Interview

- Co-founded Wafer Scale Integration (1983-88)
- Business plan:
  - WaferDisc
  - then high-speed EPROM
  - then Programmable System Devices

Eli Harari Interview

- Founded SunDisk (March 1, 1988)

SunDisk

SOLID-STATE MASS STORAGE SYSTEMS

Eli Harari Interview

- "System-Flash" was a joint effort of Eli, Bob Norman and Sanjay Mehrotra

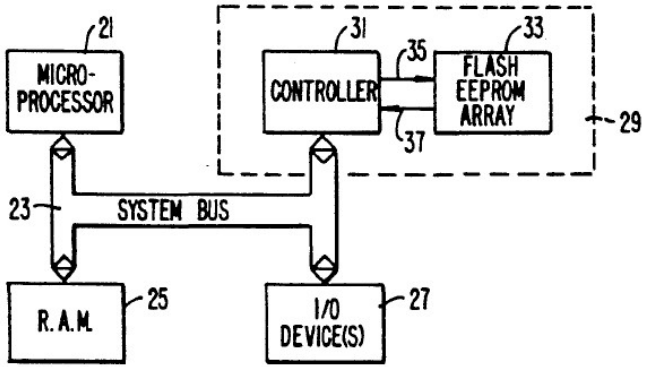


FIG._1A.

[57] **ABSTRACT**

A system of Flash EEprom memory chips with controlling circuits serves as non-volatile memory such as that provided by magnetic disk drives. Improvements include selective multiple sector erase, in which any combinations of Flash sectors may be erased together. Selective sectors among the selected combination may also be de-selected during the erase operation. Another improvement is the ability to remap and replace defective cells with substitute cells. The remapping is performed automatically as soon as a defective cell is detected. When the number of defects in a Flash sector becomes large, the whole sector is remapped. Yet another improvement is the use of a write cache to reduce the number of writes to the Flash EEprom memory, thereby minimizing the stress to the device from undergoing too many write/erase cycling.

Eli Harari Interview

- "System-Flash" included:
  - Error correction and dynamic defect mapping
  - Wear-leveling
  - Logical-to-physical mapping
  - Low stress write and erase voltages
  - Intelligent caching: speed, and write reduction
  - Garbage collection
  - Repair of disturbed cells
  - Magnetic disk drive interface

Eli Harari Interview

- "System-Flash" created an SSD
  - host-independent plug-compatible disk drive replacement
- Goal for SSD: 1 million read/write cycles
  - Also required a high-endurance flash transistor
  - Cost reductions through Moore's Law and MLC
  - Industry standard formats for removable storage

Eli Harari Interview

- IEEE talk in 1990

IEEE Electron Devices Society
Santa Clara Valley Chapter
Meeting Notice

FUTURE DIRECTIONS FOR SEMICONDUCTOR NON-VOLATILE MEMORY

Speaker: **Eli Harari**
SunDisk Corporation
Santa Clara, CA 95054.

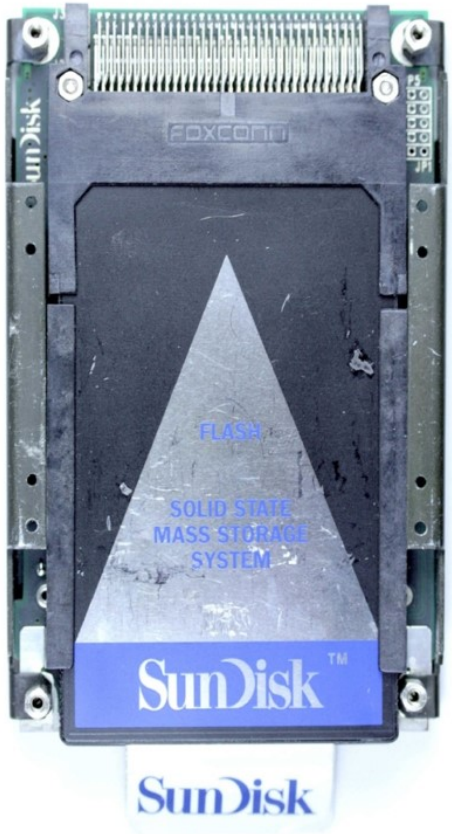
Place: Santa Clara University,
Daly Science Center
Room No. 206

Time: Tuesday, January 16th 1990, 7:30 pm.

Semiconductor non-volatile memories have in the past been an imperfect solution looking for a problem. In the coming decade, the problem, or a major market opportunity, will present itself in the form of an emerging new class of compact, portable products, such as hand-held computers, electronic notebooks, solid-state cameras, portable copiers and Fax machines, and cellular telephones. At the same time, certain types of non-volatile memory technologies, such as Flash EEPROM are at the threshold of overcoming major technological hurdles and transforming themselves from frog to prince (or king) in the new market environment.

Eli Harari Interview

- Operational device in 1990/’91
- First SSD: 20 MB ATA 2.5” device



Eli Harari Interview

- First products sold to GRiD Systems for their GRiDPad pen computer (Eli is 2nd from left; Bob Norman is 3rd from left; Jeff Hawkins at far right)

Eli Harari Interview

- Later in 1991:
  - PCMCIA SSD was available
  - SunDisk landed a contract to deliver 10,000 SSDs to IBM for their ThinkPad laptop

Eli Harari Interview

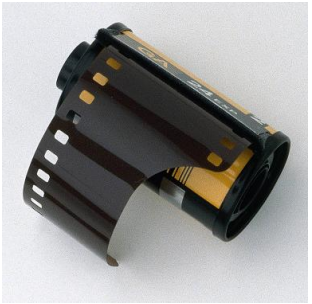
- Relationship with Western Digital, Seagate and Al Shugart

Eli Harari Interview

- Relationship with Kodak

Eli Harari Interview

- SanDisk story
  - Disruption
  - Moore's Law
  - 100,000X cost reductions over 25 years (1990-2015)



DVD™

Eli Harari Interview

- 2009 IEEE Robert Noyce Award
- 2014 National Medal of Technology and Innovation


Flash Memory
SUMMIT