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This Week's Citation Classic

Wallmark J T & Scott J H. Switching and storage characteristics of MIS memory transistors. *RCA Rev.* **30**:335-65, 1969.
[RCA Laboratories, Princeton, NJ]

In 1967 a search was on for a semiconductor counterpart to the magnetic core which until about 1973 dominated the computer memory field, but which has now been replaced by transistors. The MNOS transistor described in this paper provided a partial solution to the problem and is now used primarily as an electrically alterable read-only memory. [The *SCI*® indicates that this paper has been cited over 90 times since 1967.]

J.T. Wallmark
Research Laboratory of Electronics
Chalmers University of Technology
Rännvägen 6
S-402 20 Göteborg 5
Sweden

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"In 1967, when this work was done, computer memories were dominated by magnetic cores which could not be built by the integrated approach that was so successful for semiconductor devices. Semiconductor memory circuits encompassing flip-flop circuits or charge storage elements were not yet competitive. A new memory device was urgent —but how?

"The many drift phenomena in MOS transistors studied by S.R. Hofstein, F.P. Heiman, and others in principle constituted memory effects but seemed far from a practical memory device.[1]

"Silicon nitride was then much investigated for purposes of passivation of silicon devices. Many laboratories, about ten are referred to in the paper, had tried to stabilize MOS transistors against ion drift in the silicon dioxide by replacing it with silicon nitride. The nitride was known to be impermeable to ions and at the same time offer twice as high dielectric constant and thereby improved performance of the transistor. However, these attempts were hit by unexpected instabilities, larger and less reproducible than anything involving silicon dioxide. Prudent engineers turned their interest elsewhere. At the same time there were some suggestions, for example at the Solid State Devices Research Conference in June 1967, and more explicitly by H.A.R. Wegener and co-workers at the Electron Devices Meeting in October that year, to make memory devices using the effects. Also my co-author, J.H. Scott, had tried to make such devices. Preliminary tests by us, however, showed that memory retention was short, seconds or minutes, and writing was very slow, also seconds or minutes, and no definite threshold or saturation level could be found. The effect was very sticky and irreproducible. Serious doubts were raised that a true threshold could ever be found and a stable state reached unless the device burnt out!

"Our main contribution, which turned the situation, was the realization that under deposited nitride there must always be a layer of oxide, howevej thin, and our efforts centered around controlling this oxide thickness and quality. As the oxide should be only a few atomic layers thick and yet uniform over the entire device this was at the time unknown territory. At the end of 1967 we had practical MNOS memory devices with very fast (nanosec) switching, very long (years) retention and, above all, a controlled and reproducible process for making them. In this process the control of the oxide thickness was the key factor. We also had a beginning of an understanding of the physics of the device, much aided by discussions with E.C. Ross. The results were reported at the International Electron Devices Meeting in October 1968 and being the first description of practical MNOS transistors, have been often cited."

1. **Hofstein S R.** Stabilization of MOS devices. *Solid State Electron.* **10**:657-70, 1967.