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Control of Harmful Effects during the Program Operation in NAND Flash Memories

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Abstract

The dissertation on hand presents research on NAND flash memories, which are the most recent of today's dominant memory technologies. Its market growth fueled the cut of its product cycles to about one year and also led to increasing diversity of NAND flash products. Both make the evolutionary research and development strategy difficult to handle. Therefore, it is in urgent need to evaluate the interactions of design and technology as well as the impact of intrinsic variations and of growing harmful effects on the cells' stored information as soon as possible in the development phase of the flash memory system. However, this requires models for cell - system interaction, which are able to link the physical and electrical properties of the memory transistors with the behavior of the memory system to support the systematic decision on trade offs.

For this purpose, this work discusses the cell physics of the non-volatile semiconductor memory cell as well as its write mechanisms. The direct interaction between the programming algorithm and physical cell parameters is investigated. The NAND memory array architecture and its implications on cells' read and program operations are presented. Harmful effects on the stored information are presented, categorized, analyzed, and for this purpose conceptually separated in disturb and noise effects. Algorithmic countermeasures for floating gate cross coupling, which was seen as major blocking point for future scaling, are proposed. It is shown by worst case analysis, that floating gate cross coupling can be efficiently controlled by algorithmic countermeasures.

Taking other harmful effects into account requires a more general and versatile analysis approach. Therefore a stochastic model for the program operation is derived and experimentally verified at 48 nm ground rule. The utility and flexibility of this model is demonstrated by discussing the control of cells' V_{th} by a weak programming strategy, and by the optimization of the transistor geometry for increased V_{th} control, respectively. This improved control may be used in future NAND flash memories to either improve the memory reliability or to increase the stored data density according to the requirements of the targeted application.

By including more and more of the previously discussed harmful effects into the model for cell-system interaction, it could mature to a complete NAND memory simulator. This dissertation demonstrates the feasibility of such an approach and establishes the theoretical foundations.