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On the Read Stability of SSI Flash

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Introduction

The analog property of the stored charge in a floating gate device has been exploited for the advent of non-volatile technology, as in analog multi-level storage [1] or in digital multi-level multi-bit cell storage [2]. Since the information stored is retrieved from a Read operation, the cell read stability is of great importance and often determines the limits of performance.

For instance, in the adaptive programming method reported recently [3], the amount of charge stored in SSI cell is evaluated in each cycle for computing the next voltage pulse needed. Here the stability of the source-follower read voltage under transient condition could directly affect the program accuracy. Moreover, analog charge stored in floating gate device has been employed to trim digital-to-analog converter (DAC) [4], where the circuit performance should depend on the cell stability in time and through temperatures.

In this work, we employed a source-side-injection (SSI) Flash memory to study the cell read stability in steady state and in transient response, after cell stress aging and upon temperature variation.

Experimental

The SSI Flash cell of our study is the two poly SuperFlash ® utilizing poly-poly tunneling for cell erase and source-side injection for cell programming. The flash cells are arranged in an array of bit lines, word lines and common source lines shared by adjacent rows. The cell array operations are described in [5], where the source follower voltage is used to read the stored charge.

The source follower voltage (Vsf) *read method* is used to measure the stored charge. Fig. 1 shows how Vsf relates to the floating gate voltage Vfg, which is a direct measurement of the floating gate charge Qfg as shown in [6]. The measured value of Vsf depends on the specific procedure used, since the measured Vsf can be considered as sampled data of a continuous-time signal Vsf [7].

Two types of measurements were carried out in the *time domain*: 1) *Quasi-steady state*, here the standard bench top instruments for D. C. measurement is used, the measured Vsf is the average Vsf over a 60 Hz line cycle (16.67 ms) and the sampling rate is about once in every 1 to 4 seconds, limited by the instruments and test system; 2) *Transient response*, here mini-arrays with on chip programming circuitry is used in combination with on board signal generation, a Tektronix TDS 5054 digital scope is used, here the response time is limited to a few micro-second by the parasitic capacitance of the set-up.

Analysis, Results and Discussion

In general, the *time domain* data can be characterized by a fast moving *AC* signal superimposed on a slow varying *drift* component and. A data analysis *algorithm* has been developed to extract the *drift* and the *RMS* (root-mean-square) *parameters* from the time domain data. Then cell-to-cell comparison can be made systematically using these parameters, and various *distributions* of *read stability parameters* can be built for technology characterization. The time domain data can be convoluted and transformed into *power spectra* for *frequency domain* analysis.

Typical time domain *quasi-steady state* data are shown in Fig. 2. Here the cell is read ~ every 1.5 second, for 16.67 ms at each read sampling and the read biases are removed between read operations. The single cell data of Process A shows a small AC component on a drift background with occasional jumps, while the data of Process B features a bigger AC riding on a lower frequency varying background with an initial drift. Fig 3 shows the data of Fig. 2 are transformed to the respective *power spectra*, both exhibit a 1/f type characteristics. The high level of *white noise*, at 10^{-8} V^2/Hz, may be from signal *aliasing* [8], since in our measurements the cut-off frequency of the low-pass filter is set at 60 Hz, too high for 0.7 Hz data sampling rate.

Table I below gives examples of the read stability parameters. Here Process A and two Process C cell data are summarized. Process A shows a much smaller average RMS and Sigma RMS parameters, while two wafers of Process C show somehow varied Drift parameters; w1 is smaller than Process A and w2 bigger. Moreover, the effect of stress on cell can also be shown through changes in Drift and RMS (last row, Process A cell stressed under programming condition for 100 sec.)

Table I. Summary of Read stability parameters from two processes

	Mean Drift (mV)	Sigma Drift (mV)	Mean RMS (mV)	Sigma RMS (mV)
Process A	-1.41	1.71	0.19	0.22
Proc. C w1	-0.345	1.110	0.452	0.360
Proc. C w2	-1.81	1.88	0.50	0.48
A stressed	-6.50	---	0.145	---

To investigate the cell stability at short times, a time domain *transient response* measurement has been devised. The top plot of Fig. 4 shows the read data from a cell of Process C sampled every 20 us for the first 10 ms after the completion of a program event. The bottom plot shows the time average of data for a period of 2 ms, considerable *reduction* in *RMS* noise is observed and a drift component begins to emerge, as is consistent with signal averaging effect. Again the *transient response* data can be transformed to the *power spectrum* as shown in Fig. 5, here the 1/f characteristics is more pronounced due to a reduction of *white noise*, to 4×10^{-11} V^2/Hz.

An the 1/f characteristics may be explained as follows: 1) charge hopping among traps in the dielectrics surrounding the floating gate device will change the effective charge stored, 2) this AC conduction may result in a frequency dependent impendence as a noise source (generalized Nyquist's theorem [8]) and 3) 1/f characteristics is a reflection of charge hopping between traps [9].

The Vsf changes with the temperature as the threshold voltage and the conductance vary. Mismatch of cells and the instability in time will *broaden* the Vsf distribution of an ensemble of cells originally tightly distributed (at one temperature) as is the case shown in Fig. 6. This effect often posts as a *fundamental limit* to the cell's analog capability.

Conclusions

We have developed a systematic approach of characterizing read stability for Flash cell in general, and for SSI cell in particular. To understand the memory cell stability in time or through temperatures are essential to the development of new generation of Flash devices.

Acknowledgments

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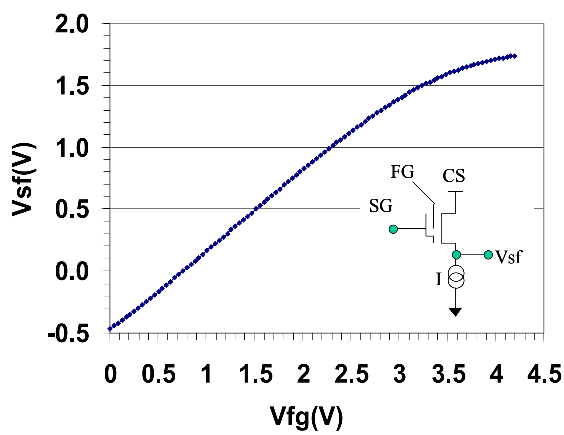

Fig. 1 Source follower voltage Vsf vs. floating gate voltage Vfg — measured from a floating gate accessible cell under read condition. The slope is the source-follower gain, ~0.7. The inset shows the cell configuration for source-follower read.

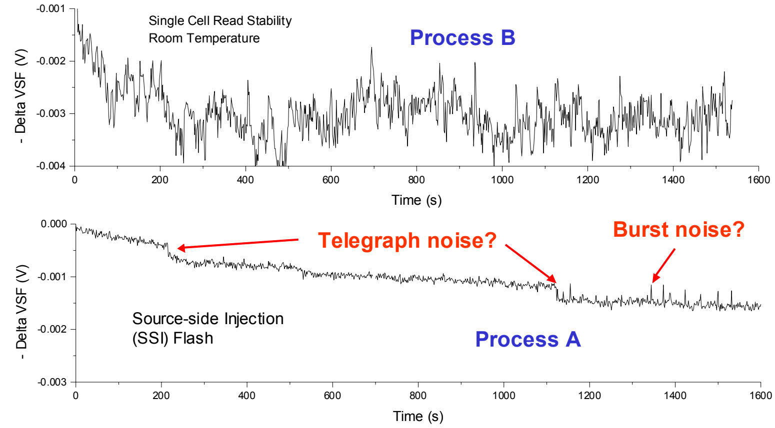

Fig. 2 Time domain *quasi-steady state* Read stability data— from two processes, Bottom plot: Process A; Top plot: Process B. ΔVsf is in reference to first read point. Erase state is in the direction of *negative* y-axis. (Sampling in linear time: ~ every 1.5 sec).

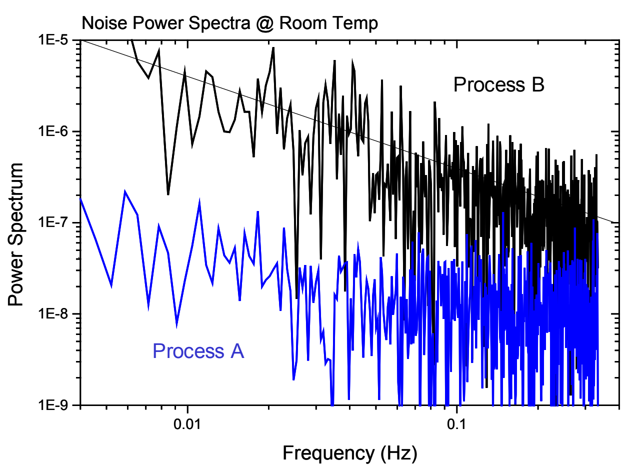

Fig. 3 Cell Noise *power spectra*— generated by FFT of the *quasi-steady state* time domain data. Process B cell is two orders of magnitude more noisy than Process A cell at extreme low frequency. The background of *white noise* is at 10^{-8} V^2/Hz as indicated by the A.

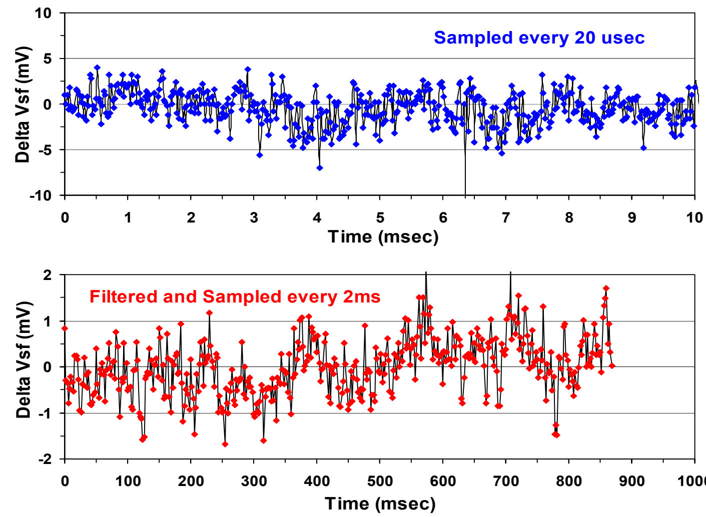

Fig. 4 Time domain *transient response* Read stability data— Top plot: data read by Tektronix TDS 5054 digital scope (shows the first 10ms after the end of program event); Bottom plot: the time average of data for 2ms. Erase state is in the direction of *positive* y-axis.

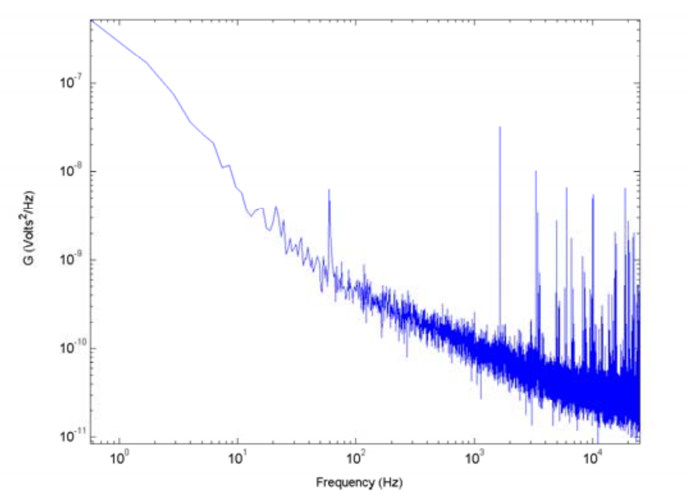

Fig. 5 Cell Noise power spectrum— generated by FFT of the *transient response* time domain data as shown in Fig. 4, where Process C cell is used, which is between Process A and Process B noise-wise. Here the floor of *white noise* is about 4×10^{-11} V^2/Hz, lower than that of Fig. 3

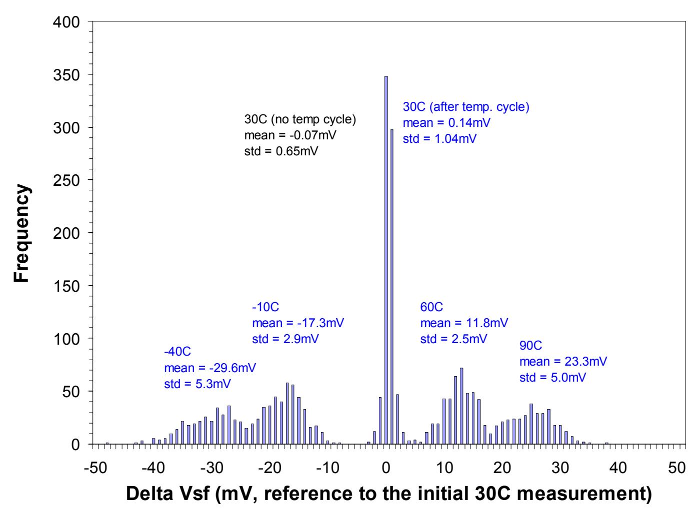

Fig. 6 Cell Vsf distributions at several temperatures—the original spread of Vsf distribution at 30C was set small by programming, but *the distribution* is inevitably *broadened by temperature* due to cell mismatches and variations in time (total of 384 cells).