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 source-follower read voltage under transient condition could directly result in parasitic noise, which may result in a frequency dependent impedance as a noise source of device will change the effective charge stored, 2) this AC conduction may result in a frequency dependent impedance 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 hysteresis in the drain current, and the mean value of Vsf may be extracted from the time domain data using a systematic approach of characterizing read stability. 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 an average RMS value of the Sigma (mV) for Process C is 4.5 times 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.)

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].

Table I. Summary of Read stability parameters from two processes

<table>
<thead>
<tr>
<th>Process</th>
<th>Mean Drift (mV)</th>
<th>Sigma Drift (mV)</th>
<th>Mean RMS (mV)</th>
<th>Sigma RMS (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proc. A</td>
<td>-1.41</td>
<td>1.71</td>
<td>0.19</td>
<td>0.22</td>
</tr>
<tr>
<td>Proc. C w1</td>
<td>-0.345</td>
<td>1.110</td>
<td>0.452</td>
<td>0.360</td>
</tr>
<tr>
<td>Proc. C w2</td>
<td>-1.81</td>
<td>1.88</td>
<td>0.50</td>
<td>0.48</td>
</tr>
<tr>
<td>A stressed</td>
<td>-6.50</td>
<td>---</td>
<td>0.145</td>
<td>---</td>
</tr>
</tbody>
</table>

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, and 2) this AC conduction may result in a frequency dependent impedance as a noise source (generalized Nyquist’s theorem [8]) and 3) 1/f characteristics is a reflection of charge hopping between traps [9].

Conclusion

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 is essential to the development of new generation of Flash devices.

Acknowledgments

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SuperFlash is a trademark of Silicon Storage Technology, Inc.

References

Fig. 1 Source follower voltage $V_{sf}$ vs. floating gate voltage $V_{fg}$ — 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. $\Delta V_{sf}$ 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 $10^{-8} \text{ V}^2/\text{Hz}$ 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 $4 \times 10^{11} \text{ V}^2/\text{Hz}$, lower than that of Fig. 3.

Fig. 6 Cell $V_{sf}$ distributions at several temperatures—the original spread of $V_{sf}$ 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).