Ferroelectric Thin Films for High Density Non-volatile Memories

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(ABSTRACT)

Ferroelectric random access memories (FRAM) are considered as future memories due to high speed, low cost, low power, excellent radiation hardness, nonvolatility, and good compatibility with the existing integrated circuit (IC) technology. The non-volatile FRAM devices are divided into two categories, based on reading technique: destructive readout (DRO) FRAM and non-destructive readout (NDRO) FRAM.

Lead zirconate titanate (PZT) is recently considered as one of the most promising materials for DRO FRAM devices due to its excellent ferroelectric properties. There are remarkable advances in the applications of PZT thin films, but the direct integration into high density CMOS devices is restricted by high processing temperatures. Hence, it is desirable to lower processing temperature and develop novel high temperature electrode-barrier layers for achieving high density DRO FRAM devices.

The NDRO FRAM devices have been developed mainly using metal-ferroelectric-semiconductor (MFS) and metal-ferroelectric-metal-insulator-semiconductor (MFMIS) structure. This devices use the remanent polarization of ferroelectric films to control the surface conductivity of a silicon substrate. The problem of the NDRO FRAM is that the actual electric field applied to ferroelectric films is very small compared to the external electric field, because of the large depolarization field in the MFS structure and the high capacitance ratio of ferroelectric capacitor and SiO_2 capacitor in series in the MFMIS structure. Since the typical ferroelectric films show very high dielectric constant over 400,

it is desired to develop ferroelectric films with low dielectric constant and low coercive electric field.

This research is primarily focused on developing low temperature processing and high temperature electrode-barrier layers for DRO FRAM application, and exploiting novel ferroelectric materials for NDRO FRAM application. The low temperature processing was achieved by a novel sol-gel processing, which takes advantage of in-situ electrode template layer, rapid heating-treatment without pyrolysis step, and molecularly modified precursors. The PZT films with various composition were also investigated as a function of Ti content. In order to study the integration issues for these PZT films, a substrate was constructed as Pt/TiN/$TiSi_2$/poly-Si, which represents a scheme of capacitor in high density DRO FRAM devices. The ferroelectric films were incorporated into the substrate, and their ferroelectric properties were investigated as a function of annealing temperature. Excellent ferroelectric properties were observed for the thin films processed at a low temperature of 500 °C as contacting between top Pt and bottom polysilicon.

The other approach we have taken to overcome the integration problems in high density DRO FRAM devices is to develop high temperature electrode barrier layers. In this research, Pt/IrO_2/Ir hybrid layers were prepared on poly-Si substrate as high temperature electrode-barriers. The PZT films fabricated on the Pt/IrO_2/Ir/poly-Si substrates exhibited good ferroelectric properties and outstanding fatigue properties after high temperature processing. It was observed from Auger electron spectroscopy (AES) profiles that the hybrid oxide electrode minimized fatigue problem by reducing the oxygen vacancies entrapment at the electrode/ferroelectric interfaces. This results indicated that Pt/IrO_2/Ir high temperature electrode-barrier layers promise to solve major problems of PZT integration into high density DRO memory devices.

For the NDRO FRAM devices, $Sr_2Nb_2O_7$ and $La_2Ti_2O_7$ thin films were prepared on Pt-coated silicon, Si(100), and Pt/IrO_2/SiO_2/Si substrates by metalorganic deposition (MOD) technique. The $Sr_2Nb_2O_7$ and $La_2Ti_2O_7$ thin films showed the dielectric constant values of 48 and 46, respectively. However, no ferroelectricity was observed at room temperature, which might be attributed to extremely small grains. Extensive studies on preparation and properties of $Sr_2(Ta_{1-x}Nb_x)O_7$ (STN) both in bulk and thin film form were carried out as a function of composition. The STN films exhibited small dielectric constant of around 46, irrespective of the composition.