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Applications of Focus Ion Beam Technique in the Characterization of Nanocrystal Nonvolatile Memory Devices

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Nanocrystal nonvolatile memory devices have attracted considerable attention due to their variety of advantages, such as high-density integration and low power consumption. The nanocrystals and some fine key components in the devices are closely related to device performance and their microstructures need to be carefully characterized and controlled. Transmission electron microscopy (TEM) is a commonly used characterization tool, however, a successful TEM experiment is strongly dependent on specimen preparation. Therefore, it is very important to prepare a site-specific electron-transparent thin specimen for TEM observation so that the observed microstructures can be correlated to device performance.

Focus ion beam in a dual-beam system is successfully applied to prepare such kinds of TEM specimens. Nanocrystal nonvolatile memory devices studied in this paper include two categories, that is, nanocrystal floating gate memory and resistive random access memory. Fig. 1a shows the cross-sectional TEM specimen of NiSi nanocrystal floating gate memory, prepared by focus ion beam (FIB) technique. The key device components consisting of NiSi nanocrystals embedded between SiO_2 tunnel layer and control layer can be clearly seen. Besides crystal size and shape, this TEM specimen allows us to obtain high resolution images of the nanocrystals down to atomic scale (Fig. 1a inset). In addition, plane-view specimens from a selected memory unite can be prepared as well (Fig. 1b), providing supplemental information about the density and uniformity of these nanocrystals sandwiched between Al electrodes. ZnO nanocystals grown on Si substrate are used for resistive random access memory. The TEM specimens were successfully prepared by FIB as well (Fig. 2a), which enable us to understand the microstructure of ZnO nanocrystals and the relationship between the nanocrystals and the substrate (Fig. 2b).

During TEM specimen preparation by means of FIB, some methods were applied to effectively protect the nanocrystals from ion beam induced damage, avoid the contamination of Pt particles in the nanocrystal area, and minimize charging problems resulted from the non-conducting oxide layers.

In conclusion, FIB is a unique and convenient technique to prepare site-specific electron-transparent thin TEM specimens. This is especially true for characterizing nanocrystal nonvolatile memory devices, where the device thickness is only a couple of hundred nanometers.

[1] The samples are provided by H.M Zhou, J.J. Ren and J. Qi from Prof. Jianlin Liu's group.

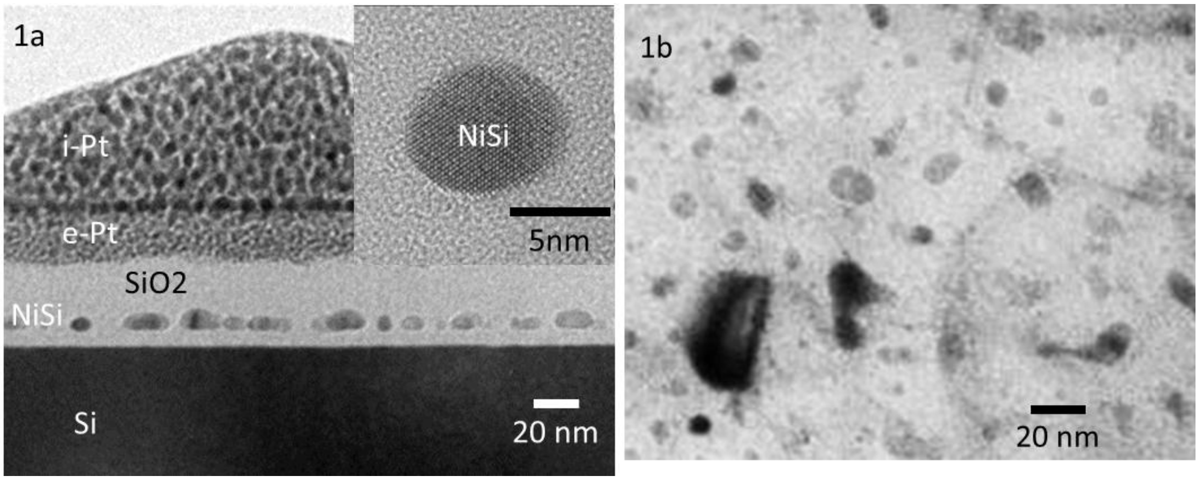

Fig. (1a) A cross-sectional TEM specimen of NiSi nanocrystal floating gate memory prepared by FIB technique and imaged by a TEM. The inset shows the high resolution lattice image of a NiSi crystal on an atomic scale. (1b) Plane-view TEM specimens from a selected memory unite, providing information about the density and uniformity of these nanocrystals sandwiched between electrodes. Please note that the big black grain is related to Al electrode instead of NiSi nanocrystals.

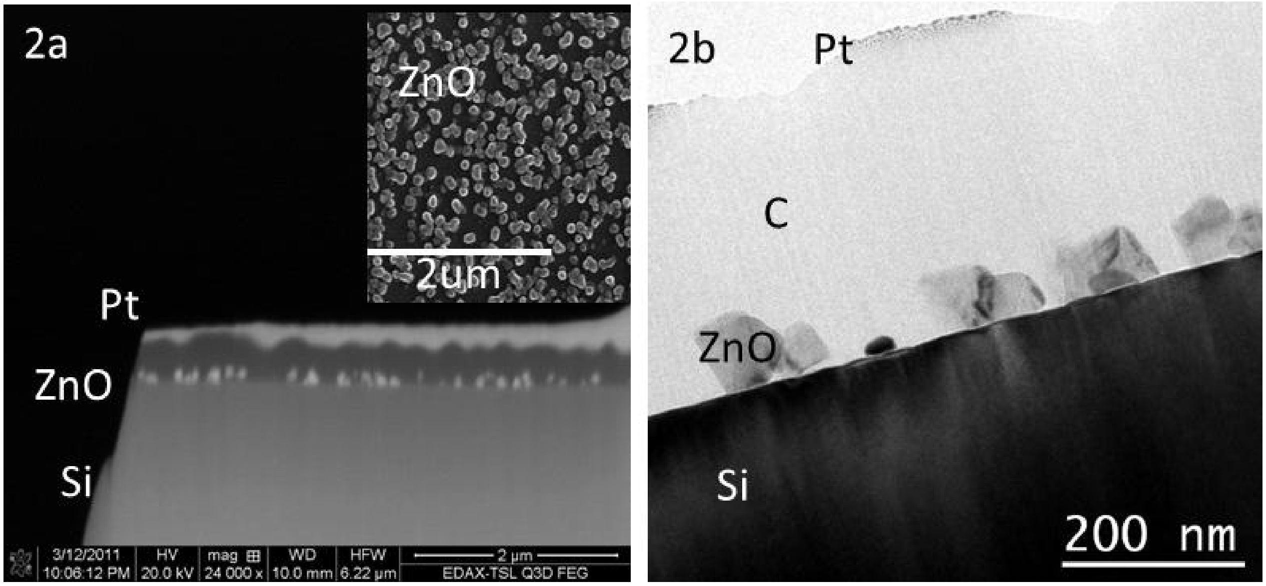

Fig. (2a) SEM image of the cross-sectional TEM specimen of ZnO nanocystals which are grown on Si substrate and used for resistive random access memory. The inset is a SEM image of ZnO nanocrystals before TEM specimen preparation. (2b) Final cross-sectional TEM specimen of ZnO nanocystals imaged in a TEM.