Application Note

Analysis of As, P dopant distribution of NMOS transistor by FESTEM & EDS

NS12001

Key Words

- semiconductor
- dopant
- FESTEM
- **EDS**
- **Quant Map**
- MSA
- **COMPASS**
- **As, P**

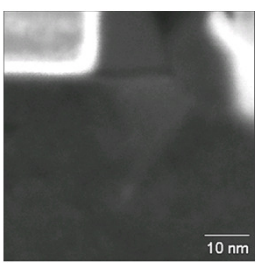
Introduction

The concentration and distribution of dopant atoms in the gate region of a semiconductor device, for example P and As in an NMOS transistor, directly affects the device performance. The characterization of these dopants, therefore, is critical to both manufacturing process control and to research and development efforts into next generation transistors. Unfortunately, the typical concentration of these dopants is quite low (less than 1000 parts per million) and the doped regions quite small (< 5 % of total region). This creates challenges in detecting and properly characterizing the dopant atom distributions. Consider, for example, Fig. 1 which shows the spectrum collected from a typical Si device structure along with the properly quantified location of the doped Si regions. The challenge of manually identifying and spatially locating the As and P dopants from the collected spectrum is apparent.

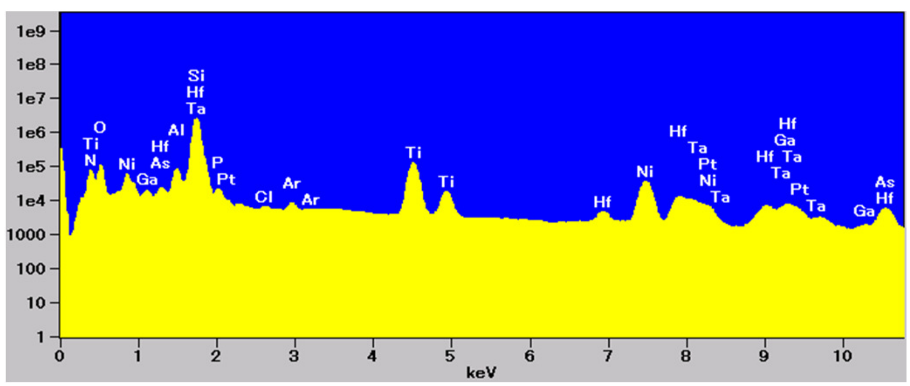
Acquisition Conditions

FESTEM	: JEOL JEM-2800
EDS Analyzer	: NORAN System 7
EDS Detector	: JEOL SDD 100 mm^2
Detector Solid angle	: 0.95 sr
Accelerating Voltage	: 200 kV
Magnification	: 4,800,000 x
Mapping Resolution	: 256 x 256
Acquisition Time	: 51 minutes
Stores Rate	: 13,200 cps
Dead Time	: 22 %

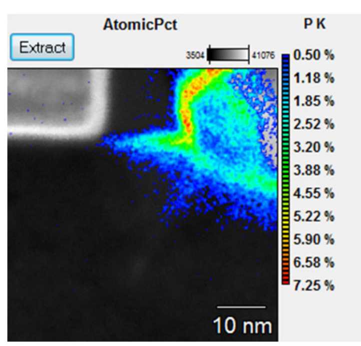
Figure 1. The image of analyzed area and the cumulative spectrum for all of the pixels in the data set



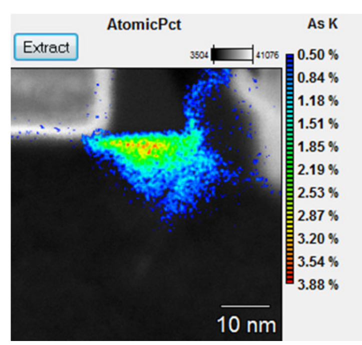
HAADF STEM image



Generally elemental analysis of silicon nanodevices is done by FESTEM and EDS. Due to the small number of dopant atoms present, it usually takes several hours to acquire statistically meaningful data. Furthermore, it is easy to overlook trace element concentrations. As the structures of the devices become smaller and more complex the analysis becomes increasingly difficult. The demand for higher sensitivity EDS mapping increases concurrently with device complexity. In this analysis, we used the latest silicon drift detector (SDD) technology with a large solid angle (0.95 sr) to analyze a current semiconductor transistor (as of the year 2012).



Quant map of P & HAADF image



Quant map of As & HAADF image

Fig. 2a. Conventional peak count

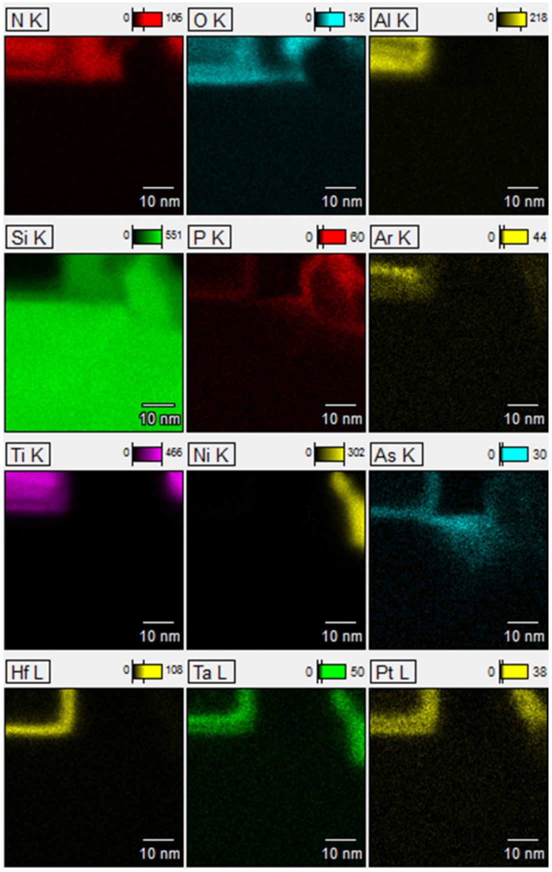
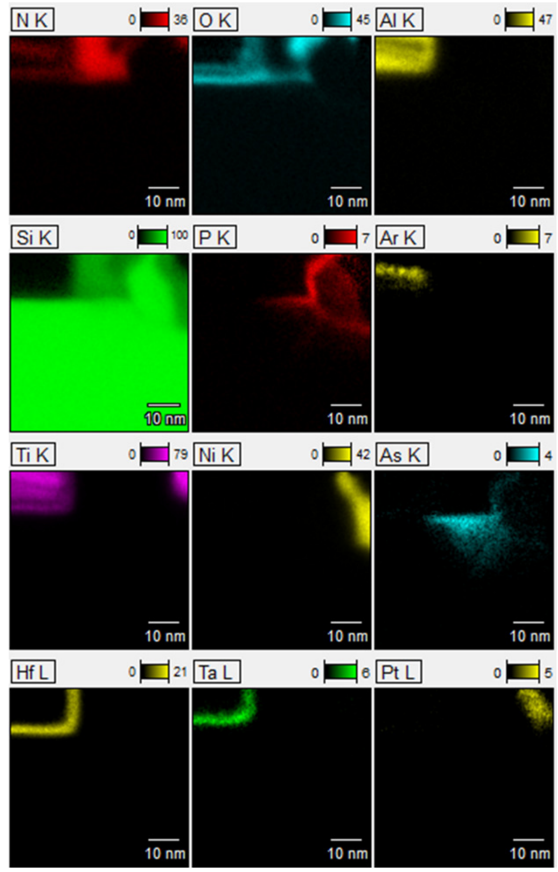
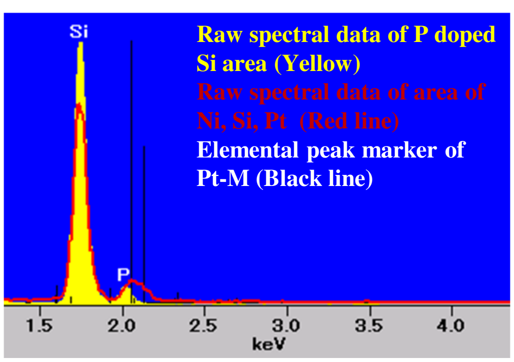


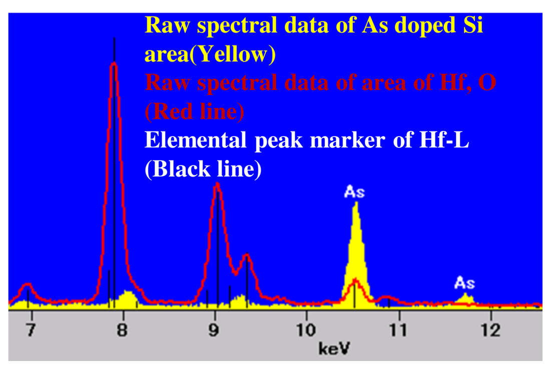
Fig. 2b. Quant map(Atomic%)



The conventional element count maps method, Fig. 2a, simply extracts the X-ray counts in a given energy range. These ranges are user-selected and likely include X-ray counts of overlapping element peaks. For example, the P-K map has information from the Pt-M peak. The As-K map has information from the Hf-L peak.

A more appropriate method for quantifying element counts in a spectrum is to deconvolute the overlapping peaks and to subtract the background. This method is termed Quant mapping. The Quant maps, Fig. 2b, clearly show the distributions of P and As atoms around the crystal defect of the Si substrate. The effect of the Pt-M peak was removed from the P-K quant map. The effect of the Hf-L peak was removed from the As-K quant map.





COMPASS automatically extracts Silicon, P doped Silicon, As doped Silicon

While the quant map method produces element maps which are corrected for peak overlaps, determining the distribution of unique phases is not clear by studying single element maps alone; particularly if the different phases contain common elements. For example, while the Si quant map (Fig. 2) benefits from removal of the background and overlapping peak (Hf-M, Ta-M peaks), identifying the specific areas of Si-dioxide and Si-nitride is not easy.

The next evolution in quantitative element mapping is the implementation of multivariate statistical analysis (MSA) in order to extract the principal components of the spectra at each pixel and to group statistically similar spectra into phases. COMPASS is a program that uses such an algorithm to do this in only a few seconds. COMPASS, at its core, is designed to determine the minimum amount of unique spectra that completely defines the overall spectral imaging data set.

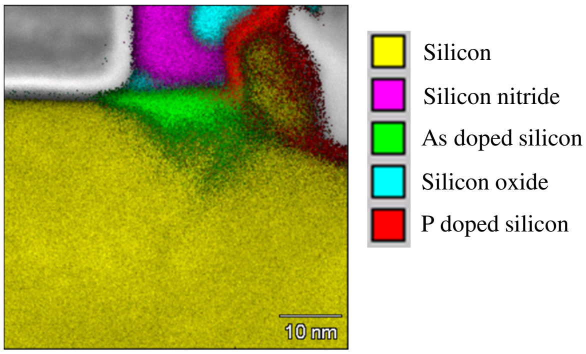
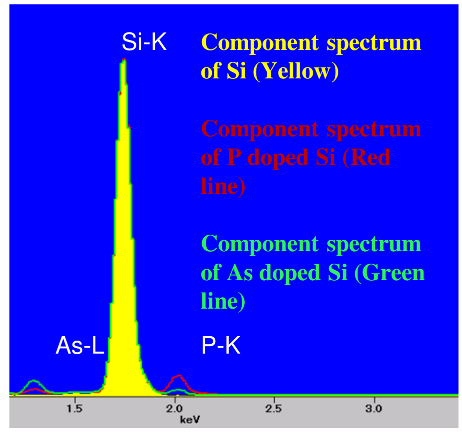
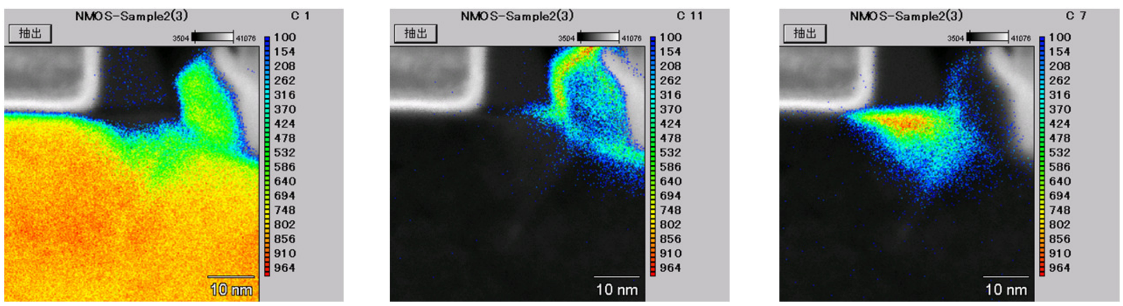


Figure 3a. Composite phase map of Si regions





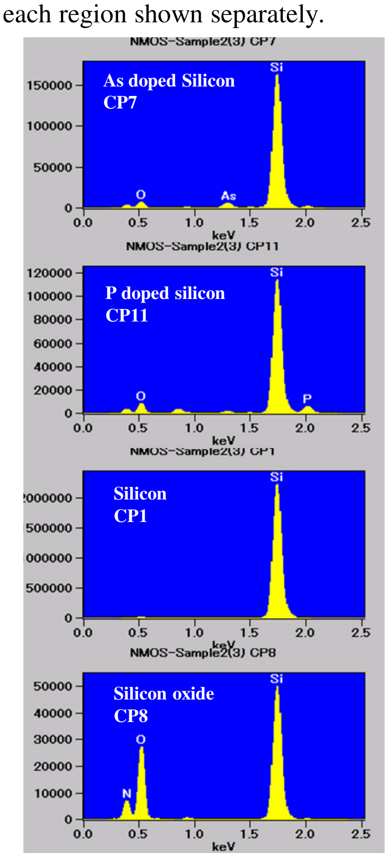
Principal component map of Si

Principal component map of P doped Si

Principal component map of As doped Si

Figure 3b. Maps of doped Si regions with each region shown separately.

The COMPASS algorithm was used to extract the distinct phases of Si. Figure 3a shows the composite phase map of each uniquely extracted Si spectrum. Figure 3b shows the maps of the doped regions of Si pulled out separate from the composite phase map (Left: undoped Si; Middle: P-doped Si; Right: As-doped Si). Figure 3c shows the unique spectra of each phase. As an added advantage, one will notice an improved Signal to Noise in these spectra as compared to the Quant maps. Because COMPASS extracts spectra that are relevant only to the specific phase of interest, the background from "non-signal" regions is eliminated. This core attribute of COMPASS assists in identifying trace elements within a phase of interest.



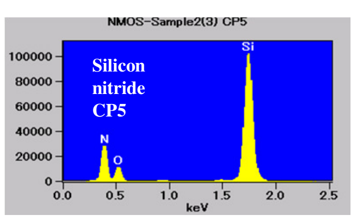


Figure 3c. Spectrum associated with each Si regions

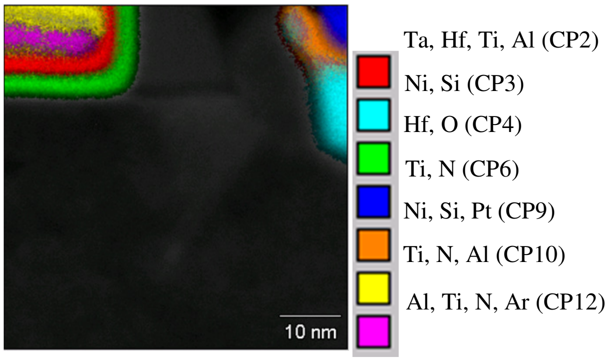
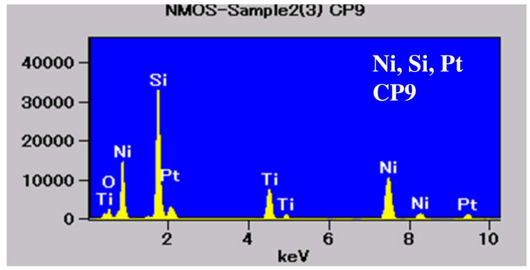


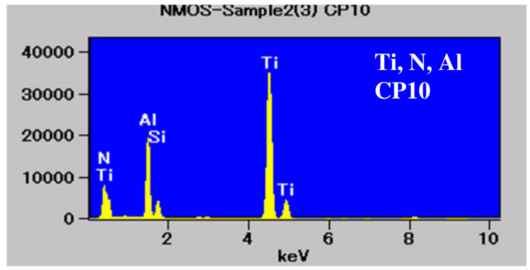
Figure 4a. Composite maps of non-Si phases

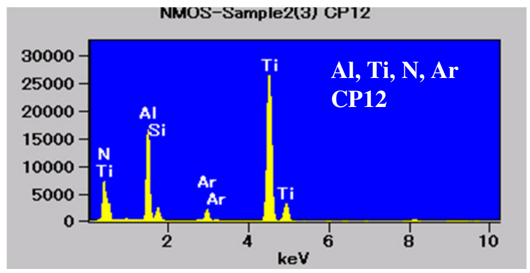
The COMPASS algorithm was also used to extract all of the non-Si phases of the device. Figure 4a shows the composite phase maps. Figure 4b contains the unique spectrum of each phase. With no pre-information about the sample, one might miss the existence of the 9th component(Ni, Si, Pt) and the 12th component(Al, Ti, N, Ar) without COMPASS.

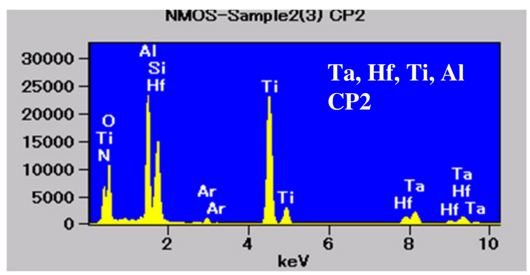
Conclusions

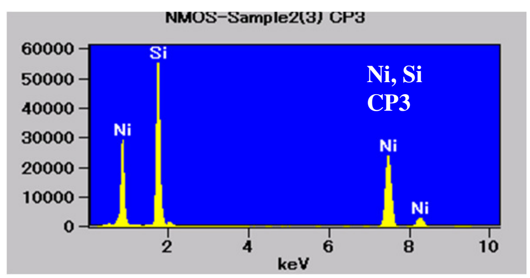
We have acquired clear distribution maps of As and P dopant atoms in a state-of-the-art NMOS transistor using a relatively short data acquisition time (about 1 hour) by using the latest FESTEM and large area SDD (100 mm^2). The removal of overlapping peaks was necessary for the analysis because the Hf-L peak overlapped the As-K peak and the Pt-M peak overlapped the P-K peak. We also demonstrated that COMPASS, which automatically extracts component spectra and maps through the use of multivariate statistics, is a strong tool for both dopant analysis and phase identification. Finally, the use of COMPASS during a live acquisition improves the efficiency of the work significantly since the acquisition can be terminated when the operator confirms that the appropriate phases were successfully identified.

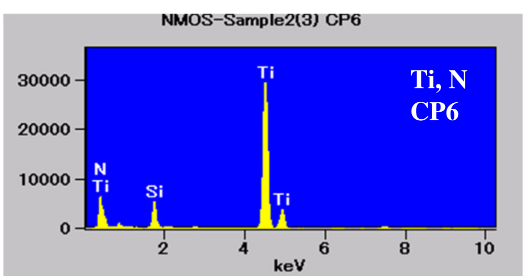












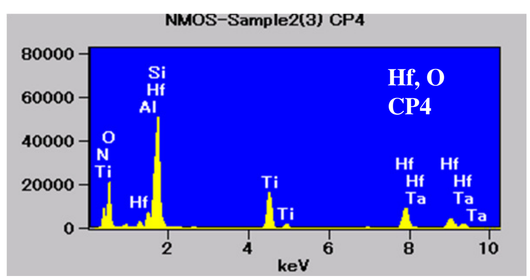


Figure 4b. Unique spectrum from each phase.

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