Atomic resolved EELS analysis across interfaces in III-V MOSFET high-k dielectric gate stacks

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N-type III-V materials are one of the potential candidates to replace Si MOSFET technology. In particular n-type GaAs shows carrier mobility 5 times higher than that of Si [1]. So far, the realization of GaAs based MOSFET devices have been limited by the difficulties of making a good dielectric oxide layer in terms of leakage current and unpinned Fermi level. However, it has been shown that the realization of dielectric gate stacks consisting of a template layer of amorphous Ga_2O_3 followed by amorphous GdGaO can leave the Fermi level unpinned and a low leakage current [2]. Using this approach GaAs based MOSFETs devices that show useful electrical properties have been created. The performance of these transistors is strictly related to the device architecture and, more importantly, the quality of the interface between the GaAs and the oxide layer. Scanning Transmission Electron Microscopy ((S)TEM) related techniques are particularly suited to investigate the structure and the chemistry of this interface. In particular the combination of electron energy-loss spectroscopy (EELS) and STEM acquisition enables spectrum image (SI) the acquisition of one or more spectra at each point of the scanned image. With the development of aberration corrected microscopes EELS SI is now routinely used to investigate the chemistry and the elemental distribution across interfaces with atomic resolution. However when the sample is electron beam sensitive, atomic resolution level EELS analysis becomes more challenging unless fast spectrometers are used. This is the case for the Ga_2O_3 which tends to crystallize under the beam The GIF Quantum [3] with its spectral rate of over 1000 spectra per second allows the acquisition of atomic EELS maps at a speed fast enough that damage caused by the interaction of the electron beam with the sample is limited. In addition, the lens system present in the GIF Quantum® with the capability to correct the aberration up to the 5th order, leads to the ability of using high collection angles allowing more signal to enter the spectrometer whilst maintaining the energy resolution.

We applied the EELS SI approach to the characterization of the GaAs/Ga_2O_3 interface with a spatial resolution of just over 1Å. According to [4] the chemistry across the interface region largely influences the electrical properties of the dielectric stack and more importantly is the reason why the Fermi level is unpinned. The material was grown by MBE on a semi-insulating GaAs substrate using a dual chamber system. 30nm of amorphous Ga_2O_3 was grown on the GaAs substrate. 40nm of Pt was electron beam evaporated onto the Ga_2O_3. This layer is important in order to protect and preserve the quality of the sample from the damage that might occur during the specimen preparation process. TEM specimens were prepared using conventional cross-sectioning involving at the final stage ion-milling using a Gatan PIPS. EELS data was acquired using the STEM-EELS system at Florida State University which is composed of a probe-corrected ARM 200 equipped with cold-FEG and a GIF Quantum as EELS spectrometer. The experimental conditions set for the EELS SI experiment were first tested across a region in the GaAs substrate. Here the Ga $L_{2,3}$-edges at 1115eV and the As $L_{2,3}$-edges at 1323eV were extracted, mapped out and shown in the colorized EELS elemental map in Figure 1. These maps show high contrast and more importantly the resolution needed to resolve the dumbbell in the crystalline GaAs [110]. Here the Ga is sitting on the left hand side of the dumbbell whereas the As on the right. After these promising results that prove the high level of spatial resolution achievable by EELS SI, the area across the GaAs/ Ga_2O_3 interface was analyzed. The area in the green box shown in Figure 2a was scanned by the electron beam during the acquisition of the EELS SI which took just about 30 seconds. The high-resolution

ADF STEM image in Figure 2a does not many details and yet the elemental distribution at the interface appears to be unknown. However, as shown in the colorized EELS elemental map of the O K-edge at 532eV, the Ga $L_{2,3}$-edges at 1115eV and the As $L_{2,3}$-edges at 1323eV in Figure 2b, it is possible to tell that last dumbbell right at the interface is less populated and contains both As and Ga. The region between the GaAs and the Ga_2O_3 seems to be amorphous and enriched in Ga. According to [4] in the interface region there should be a monolayer of Ga_2O which basically unpins the Fermi level. We will present further results from this sample and also from the corresponding sample oriented along the [1-10] direction giving a clear and complete understanding of the interface which is not achievable using high-resolution ADF STEM imaging alone.

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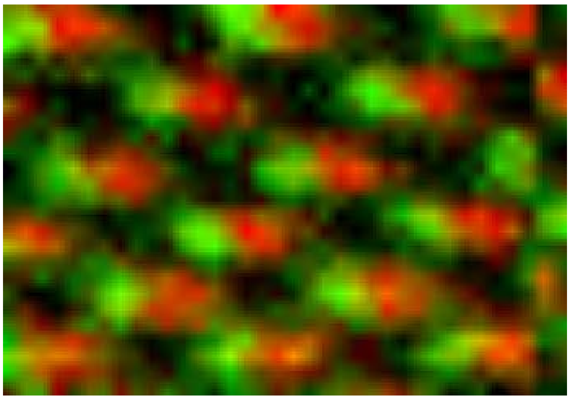

***Figure 1**: Colorized EELS elemental map of As $L_{2,3}$-edges at 1323eV in red color and Ga $L_{2,3}$-edges at 1115eV in Green. The resolution and the contrast shown by these EELS maps are very high.*

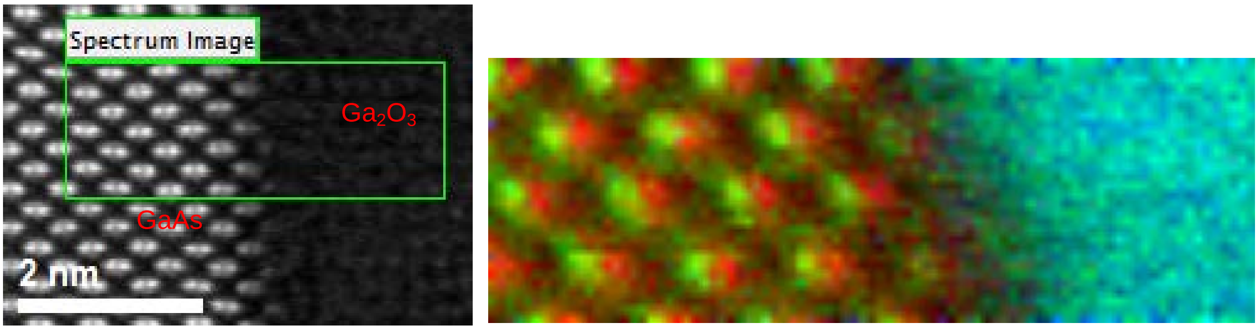

***Figure 2a**: High-resolution ADF STEM image. The green box is the area where the beam was scanned during the acquisition of the EELS SI. **Figure 2b**: Colorized EELS elemental map of As $L_{2,3}$-edges at 1323eV in red color, Ga $L_{2,3}$-edges at 1115eV in Green and O K-edge at 532eV in blue. The details that this image shows at the interface are visible in the ADF STEM image.*