Characterization of Point and Extended Defects in β-Ga_2O_3

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β-Ga_2O_3 has emerged as a promising candidate material for high performance ultra wide band gap (UWBG) electronic, optical, and power device applications, due to its unique advantages as a transparent conductive oxide (TCO) including a high breakdown voltage and its availability as inexpensive high quality bulk grown single crystals. *β*-Ga2O3 is conductive while showing transparency into the ultraviolet region because of its ~ 4.9 eV effectively direct band gap which is one of the highest amongst wide band gap materials [1]. Despite these advantages, its basic properties are not fully understood, resulting in the inability to be properly controlled. In *β*-Ga2O3, the lack of understanding of its intrinsic n-type behavior, difficulty in p-type doping, low doping efficiency, and impurity contribution to electronic/optical properties can be directly linked to the point defects present [2]. Obtaining important point defect information, specifically, on the distribution of cation and oxygen vacancies, extended defects, and how point defects are connected to local atomic distortion and interact to form defect complexes will be the key to controlling its important properties (Fig. 1). Establishing the structure-property relationship in *β*-Ga2O3 has become increasingly important due to the recent progress in the growth of thin film *β*-Ga2O3 for device applications [3].

The characterization of point and extended defects in *β*-Ga2O3 will require a technique with high resolution and precision to identify the positions of the defects as well as the structural changes that they induce. Here, we show the microscopic investigation of defects in bulk and thin film *β*-Ga2O3 to establish their relationship to electrical and optical properties using scanning transmission electron microscopy (STEM). Our technical focus will be on using and further developing our electron channeling contrast method that relies on the de-channeling of electrons to enhance the contrast of individual point defects, including vacancies and impurity atoms [4]. This method is demonstrated using a traditional ADF detector and also by collecting 4-dimensional STEM data from a pixelated fast STEM detector. Our recent results from bulk *β*-Ga2O3 (Fig. 2), and α and *β*-Ga2O3 thin films grown by both low pressure chemical vapor deposition and molecular beam epitaxy will be presented. A thin and clean sample must be prepared to extract structural information from the defect. TEM sample preparation and results from focused ion beam (FIB) prepared, wedge polished, and membrane samples will also be discussed.

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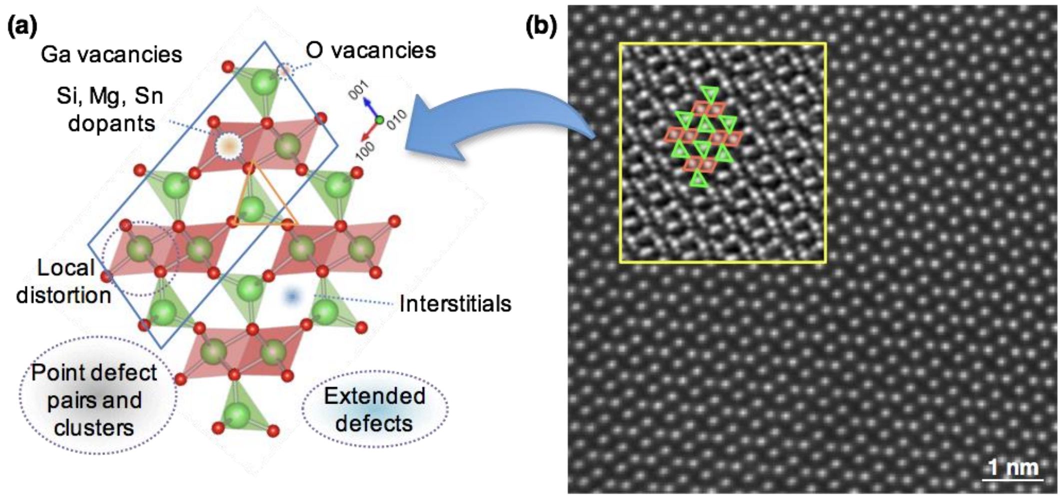

Figure 1. (a) Potential defects in *β*-Ga2O3 under investigation. (b) An experimental STEM HAADF image of [010] unintentially doped bulk *β*-Ga2O3 with the corresponding integrated differential phase contrast (iDPC) image overlaid and the crystal structure identified.

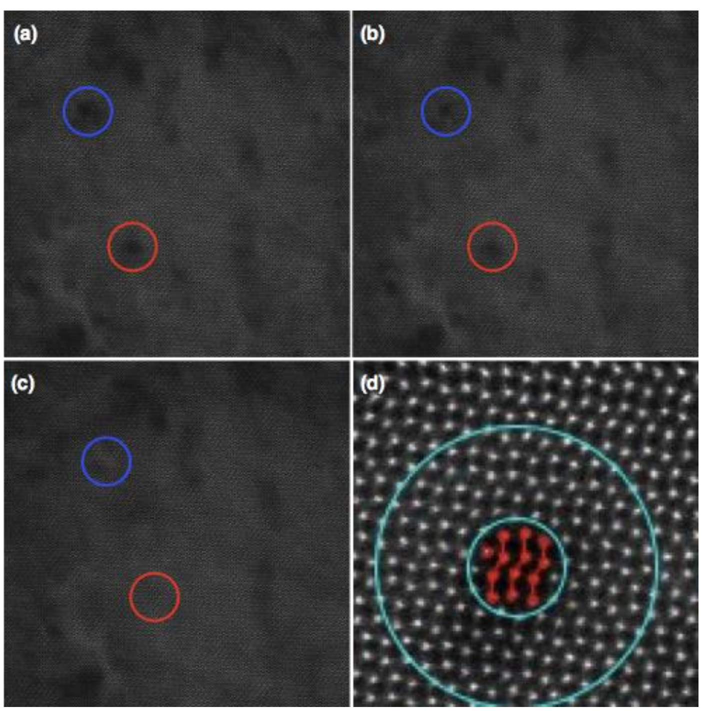

Figure 2. (a-c) Consecutive STEM HAADF images of Sn-doped bulk *β*-Ga2O3 along the [010] orientation show circular pockets of low intensity disappearing. (d) Experimental STEM image of the same sample reconstructed from a 4-dimensional data set for high angles shows atomic column displacement at the "core" (circled red columns) surrounded by strain.