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Direct Comparison of Convergent Beam Electron Diffraction and Geometric Phase Analysis for Local Strain Measurement

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Many of today's microelectronics devices are taking advantage of localized straining of silicon for enhanced performance. Different techniques have been employed for the quantitative measurement of these elastic strains. Ideally the technique used for this should provide nanometer scale spatial resolution and sensitivity to changes in strain of 0.2% or less. For these reasons both convergent beam electron diffraction (CBED) and geometric phase analysis (GPA) have been used by several researchers and have provided useful results [1-6]. However, there has been little in the way of direct comparison of the strain values measured using these two different techniques. Such an experiment would highlight the relative advantages and limitations of these techniques for strain measurement.

In this study, the gate channel of a strained enhanced p-type metal oxide semiconductor field effect transistor (MOSFET) was analyzed using both GPA on high angle annular dark field – scanning transmission electron microscopy (HAADF-STEM) images and CBED. Recessed SiGe regions on either side of the channel were incorporated into the device to introduce a lateral compressive strain in that region. The specimen analyzed in this study was prepared via a lift-out technique using an Omniprobe Autoprobe 250 in an FEI Nova 200 focused ion beam – scanning electron microscope (FIB-SEM) instrument. The specimen thickness was approximately 320 nm in order to produce good quality CBED patterns. While this thickness is not ideal for the high resolution imaging necessary for GPA analysis, reasonably good images were obtained. An FEI Tecnai F20 transmission electron microscope (TEM) operating in STEM mode was used to collect zero-loss energy filtered CBED patterns. These CBED patterns were obtained at several distances below the base of the gate using three different zone axes: <230>, <340>, and <670>. An FEI Titan 80-300 with a Fischione annular dark field detector was used to acquire the HAADF-STEM images for GPA.

Fig. 1 shows the strain profiles from the center of the channel as a function of distance below the gate as determined from CBED and GPA for the $[1\bar{1}0]$ and [001] directions. The uncertainties for these values are shown with the error bars in the plot. Both methods display very good agreement on the strain trends and on the relative changes in strain values as a function of distance below the gate for both the $[1\bar{1}0]$ and [001] directions. However, they disagree on the absolute strain values determined at each point. Although there are several distances from the gate for which the data from the two techniques are equal within the uncertainties of the measurements, these data are clearly consistently offset from each other over the whole range. The trend lines in the figure help elucidate this. The offset is ~0.2% in the $[1\bar{1}0]$ strain values and ~0.3% in the [001] strain values.

This likely stems from how the reference strain is defined in each technique. In both techniques one point is assumed as being free from strain in all directions and all of the other measured strain values are referenced from that zero strain position. For the CBED data, a CBED pattern was collected from the silicon substrate at a distance of greater than 500 nm from the device. This pattern was used to determine the exact accelerating voltage value to use when fitting all of the subsequent experimental patterns. For the GPA data, the reference point must be contained within the HAADF-STEM image, so the point furthest from the device in the image was used. In this case, that was 230 nm from the device. Previous CBED work on this and similar samples has shown HOLZ line splitting, which is indicative of stress relaxation, up to 500 nm below the device [7]. Therefore, the probable cause of the consistent offset observed in these strain values is that the reference point for the GPA data was likely not entirely free from strain.

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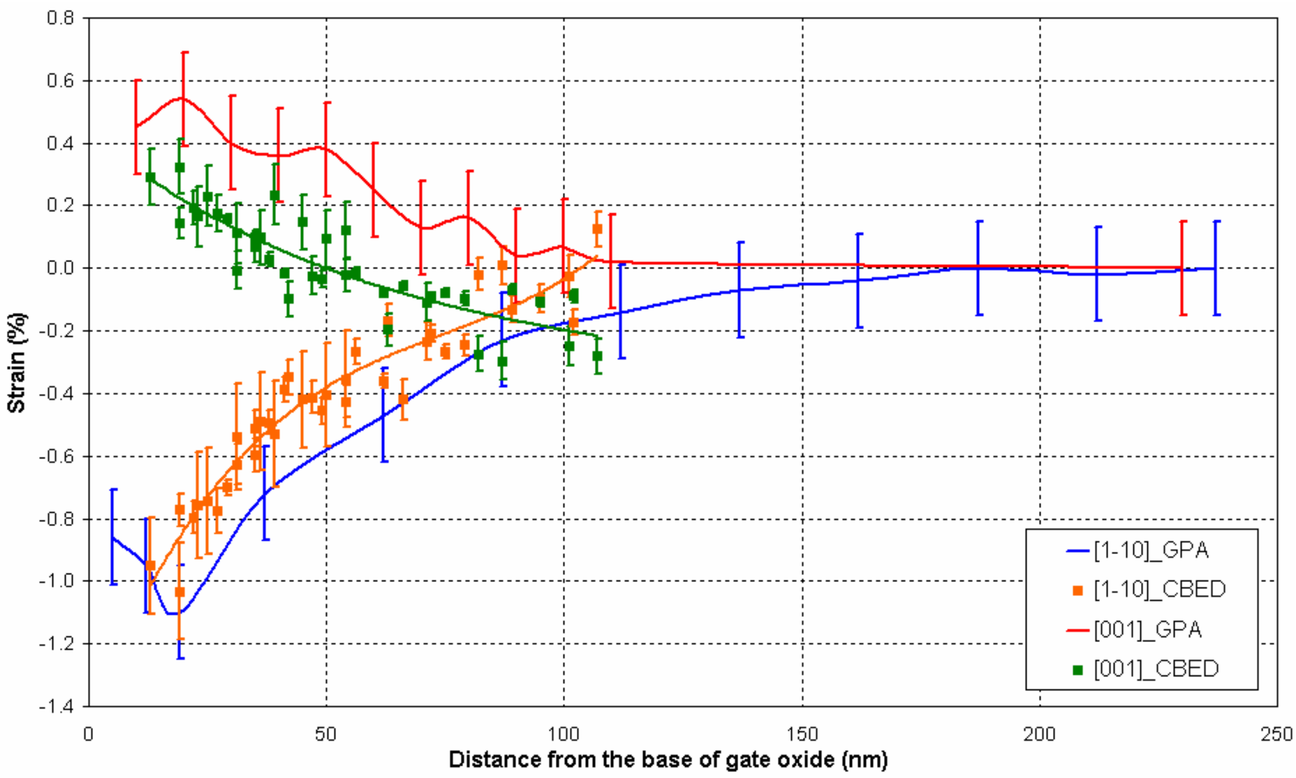

Figure 1. Strain as a function of distance from the gate of a strained silicon MOSFET as determined by CBED and GPA. Error bars for both sets of data indicate the uncertainties in the strain values. A 40 nm wide region was averaged to produce the GPA data.