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Analysis of Inter-and Intra-Grain Defects in Electrically Characterized Poly-Si Nanowire TFTs by Multicomponent DF Imaging Based on NBD-2DI

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Abstract

We revealed inter-and intra-grain defects in the channels of the electrically evaluated poly-Si nanowire (NW) thin film transistors (TFTs) based on nanobeam electron diffraction two dimensional imaging (NBD-2DI). As the mobility degradation of the poly-Si NW TFT is caused by both inter-and intra-grain defects [1], we have developed a technique to show such defects, which was named multicomponent dark-field (DF) imaging. We visualized the grains by color and identified crystalline structures of grain boundaries (GBs) by using NBD patterns in the nm-scale channels. In addition, the gradation in the same colored grains indicates lattice distortions or defects. This analysis is practically impossible by using conventional scanning/transmission electron microscopy (S/TEM).

1. Introduction

Poly-Si NW TFTs have attracted much attention as key components in 3D LSI [2,3]. Large grain size in the poly-Si channel is one of important factors for high mobility. On the other hand, our group has reported the high-performance poly-Si NW TFTs having larger grain size compared to channel size. It has been revealed that mobility of high performance TFTs is determined by the defects inside the grains as well as GBs [1]. However, the dominant factors of individual Tr. characteristic have not been fully elucidated because of the difficulties to correlate the channel crystallinity with the electrical properties in the same nm-scale TFT. Hence, the technique to investigate the position and number of both inter-grain and intra-grain defects is very important.

Recently, we have developed a new method to investigate the channel crystallinity of the same TFT that was electrically evaluated (Fig.1) [4]. We found that the continuous grain without GBs from source to drain is the key for high I_{ON} by NBD-2DI, the crystallinity imaging technique based on the two-dimensionally mapped NBD patterns. The technique includes diffraction contrast, that is, bright field (BF) and all DF images corresponding to all diffraction spots. It is practically impossible to obtain such images using conventional S/TEM.

In this work, we analyzed the NBD patterns in more detail by focusing on each diffraction pattern and its intensity distribution in order to identify the grains inside the channel as well as the crystalline structures of GBs. We also tried visualizing presence of defects inside grains.

2. Devices and experimental procedure

Process flow of poly-Si NW Tr. [1] and experimental procedure are shown in Fig. 2. Optimized *a*-Si deposition and crystallization annealing, and poly-Si thinning process was used to achieve high I_{ON} with low I_{OFF} [1].

STEM/NBD specimens were prepared by removing gate poly-Si and the substrate while leaving a small amount of gate insulator by focused ion beam (FIB) technique utilizing the triple-beam FIB instrument [4].

NBD-2DI was performed at 1 nm intervals in scanning NBD mode at accelerating voltage of 200 kV. Both high spatial resolution (3 nm) and large map (0.5×0.5 μm^2) were achieved by acquiring over 40,000 NBD patterns. An equivalent BF-STEM image can be reconstructed by the intensity of transmitted electron in NBD pattern recorded in each scanning position; also, DF-image showing each grain can be reconstructed by the intensity of diffraction spot. The grains were then visualized as multicomponent DF image, which is the superimposed DF images for each grain. Similar color region means similar grain and gradation refers to the crystallinity inside grains.

3. Experimental results and discussions

I_d-V_g curves of 68 Trs., extracted *S* factors and V_{th} show large variations in spite of the same process (Figs. 3(a-c)); the highest I_{ON} is 3 times higher than the lowest I_{ON}. Tr. with lower *S* factor and V_{th} tend to show higher I_{ON}. 5 Trs. having relatively high and low $I_{ON,}$ and mid I_{ON} were selected for NBD-2DI analysis and the representative example are shown here.

Figure 4 shows a typical plan-view BF-STEM image of a TFT. The range of interest indicates the NBD mapping area. Figures 5(a,b) show the NBD-2DI results of BF and multicomponent DF images, and NBD pattern in each position for H1 and L1, respectively.

For H1 (Fig. 5(a)), BF-STEM image shows uniform contrast in the channel though line contrast are observed as noted by #1 and #2. We can clarify whether the crystallographic orientation is similar by using NBD pattern in each position. The NBD patterns at points A-C and D are different; in other words, contrast#1 is GB. The multicomponent DF image visualized the large continuous grain from source to drain and the small grain. In addition, we observed additional spots in the NBD pattern at point C compared to those at points A and B. Such subtle difference of the diffraction intensity is often caused by local lattice distortion and defects, resulting in contrast #2. This indicates the potential of NBD-2DI technique for the visualization of lattice distortion or defects inside a grain.

For L1 (Fig. 5(b)), the multicomponent DF image revealed that the crystallinity of L1 is divided into upper and lower grains. We can identify the crystallographic orientations of the grains by NBD patterns. The specific relation between the upper and lower grains, such as tilted boundary, was not confirmed. Hence, the channel of L1 is constructed from two grains having a random boundary connected in

series. The channel having continuous grain for H1 and the channel separated by random boundary for L1 was revealed by multicomponent DF imaging to be responsible for their high I_{ON} and low I_{ON}, respectively.

4. Conclusions

Both inter-and intra-grain defects inside the channels were visualized for individual poly-Si NW TFTs by developed multicomponent DF imaging technique. Our technique can be applied to the analysis of various devices and materials composed of nm-scale crystal grains.

References [1] M. Oda *et al.*, IEDM2015, p. 6.1. [2] C.-C. Yang *et al.*, IEDM2013, p. 29.6. [3] P. Batude *et al.*, VLSI2015, p.T48. [4] T. Asano *et al.*, Proc. IRPS2017, 5C-2 *late news*.

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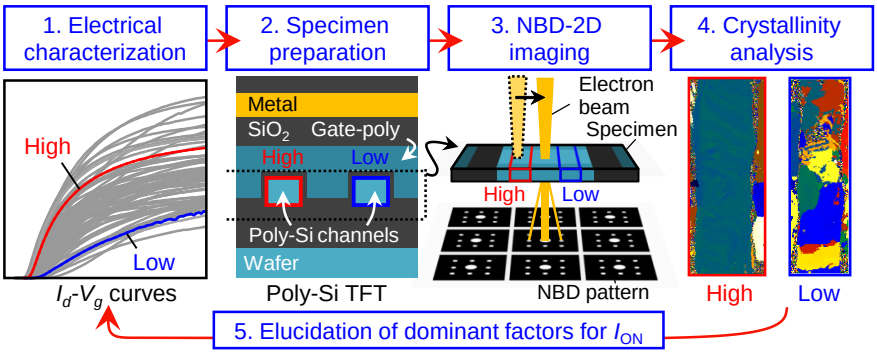

Fig. 1: Conceptual view of one-to-one correspondence between channel crystallinity and electrical properties in the same poly-Si TFT [4]. The channel of the same TFT that was electrically evaluated was characterized by developed FIB technique and NBD measurements. The dominant factor of I_{ON} is consequently elucidated.

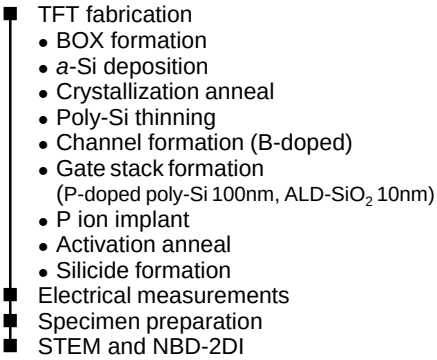

Fig. 2: Process flow of poly-Si NW TFTs with L=230 nm, W=80 nm, T=50 nm and experimental procedure.

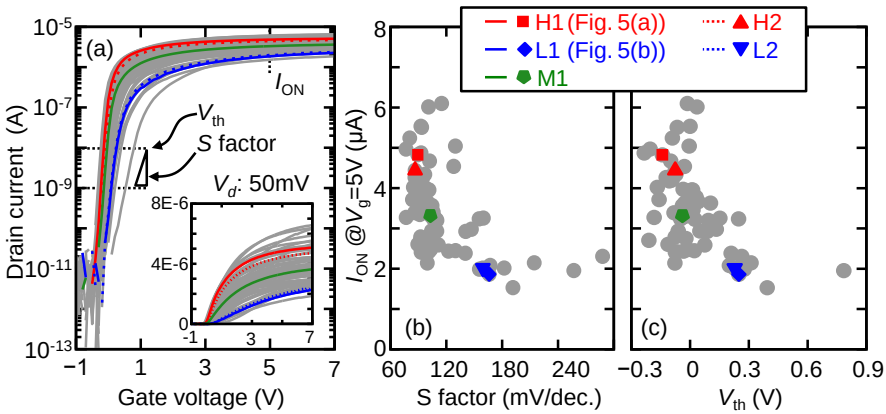

Fig. 3: (a) I_d-V_g curves of poly-Si TFTs measured at 300K. Inset shows I_d-V_g in linear scale. (b) Relationship between S factor and I_{ON}. (c) Relationship between V_{th} and I_{ON}.

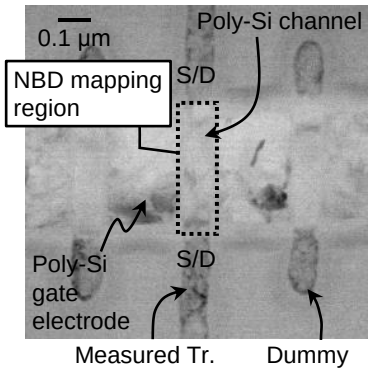

Fig. 4: Typical plan-view BF-STEM image. The area surrounded by dashed line was mapped by NBD.

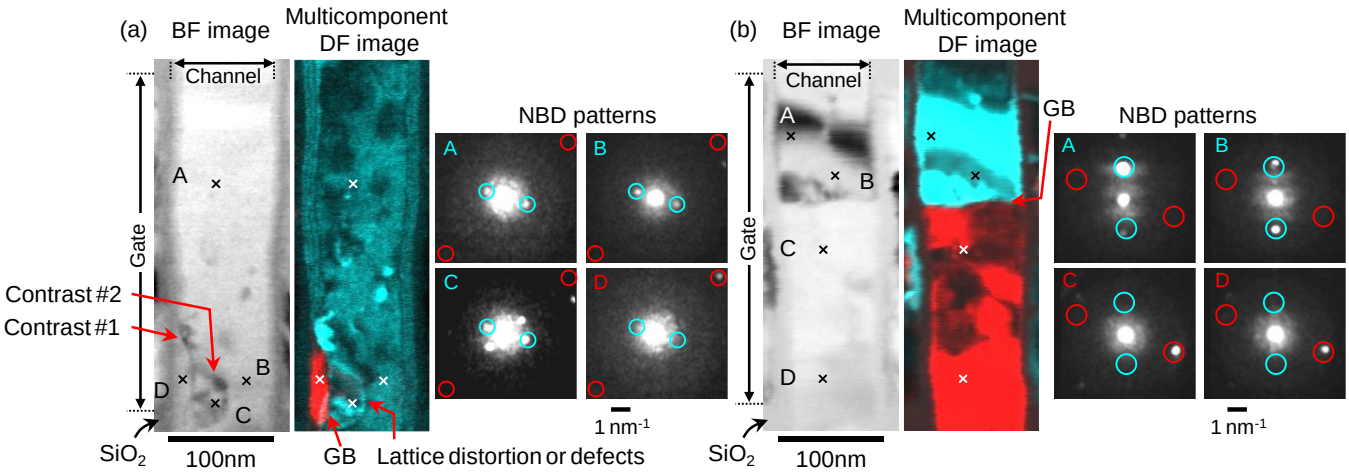

Fig. 5: Results of NBD-2DI for samples (a) H1 and (b) L1. Equivalent BF-STEM image was reconstructed from the intensities of transmitted electron in NBD patterns. Multicomponent DF image was constructed from superimposed two DF images reconstructed from the intensities of selected diffraction spots, indicated by red or blue circles in NBD patterns. Similar color region means similar grain and gradation refers to the crystallinity inside grains.