Formation of Si-Nanosheet from Si0.7Ge0.3/Si/Si0.7Ge0.3 Stacked Layers by CF4/H2 Plasma

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Abstract

Gate-all-around field-effect transistors (GAA-FETs) have been attracted much attention as one of the most promising candidates for Fin-FET replacement in transistor size scaling, and well-switching characteristic (1). Furthermore, by introducing a vertically-stacked Si-nanosheet structure, greater drive currents with greater effective channel widths under the same footprint are obtained. To fabricate the Si-nanosheet structures, dry etching process for the Si/SiGe multi-layered fin-structures fabrication and selective lateral etching of the sacrificial SiGe are essential. However, surface roughening and defect formation of the Si-nanosheets by the lateral etching are critical for device performance and yield management. In this work, we studied selective lateral etching of Si0.7Ge0.3/Si/Si0.7Ge0.3 layer stacks using CF4/H2 plasma and evaluated energy distributions of defect states in the stripped Si-lamella part after the etching of Si0.7Ge0.3 layer by total photoelectron yield spectroscopy (PYS).

Si0.7Ge0.3/Si/Si0.7Ge0.3 stacked layers were epitaxially grown on n-Si(001) using H2-SiH4-GeH4 at 600ºC by reduced-pressure chemical vapor deposition. The thickness of each layer was ~50 nm. Then, ~0.1 mm-width resist-patterns were fabricated in the <110> direction by photolithography. After that, Si0.7Ge0.3/Si/Si0.7Ge0.3 line-patterns were formed by vertical etching using the 13% H2-diluted CF4 plasma under substrate bias application at 200 W. Subsequently, lateral etching was carried out using the 5% and 10% H2-diluted CF4 plasma without any external bias in the same chamber. Herein, the flow rate of total gas and substrate temperature were kept constant at 100 sccm and 20ºC, respectively.

From SEM image taken after etching using the 13% H2-diluted CF4 plasma at an applied bias of 200W, we successfully demonstrate vertical etching (Fig. 1(a)). Subsequent etching using the 10% H2-diluted CF4 plasma without bias application, selective etching of the Si0.7Ge0.3 layers in the lateral direction was confirmed (Figs. 1(b, b')). This result indicates F-radicals in CF4/H2 plasma are effectively acted to cleave the Si-Ge/Ge-Ge bonds rather than the Si-Si bonds since binding energy of the Si-Ge/Ge-Ge bonds is lower than that of the Si-Si bonds. In addition, fluorocarbon deposition on Si-sidewall might be acted as passivation layer because the fluorocarbon are deposited on Si than on Si0.7Ge0.3 during irradiation of CF4/H2 plasma (2). By reducing the H2 dilution ratio to 5%, the selectivity of the etching rate is improved, as a result formation of the Si-nanosheet become obvious with increasing etching time (Figs. 1(c, c')). This result indicates that decreasing in the H2 dilution ratio promotes etching selectivity because F-radicals increase exponentially with a decrease in the H2 dilution ratio (3). We also evaluated RMS roughness of the Si-nanosheet (Fig. 2). It can be seen that RMS roughness of the Si-nanosheet formed by using CF4/H2 at dilution ratio of 10% and 5% are as low as ~0.51 and ~0.55 nm, respectively. The surface roughness of the Si-nanosheet are slightly increased from the initial Si surface (Si/Si0.7Ge0.3/n-Si(001) surface (RMS: ~0.11 nm)), however the surface roughening of the Si-nanosheet is successfully maintained.

To evaluate energy distributions of defect states in the Si-layer, we measured PYS of Si/Si0.7Ge0.3 structure, where the Si0.7Ge0.3 top-layer was completely etched by CF4/H2 plasma (Fig. 3). We also show the PYS of the ~50 nm-thick as deposited Si-layer on Si0.7Ge0.3 as reference. Although the yield in the photon energy region from ~4.3 to ~5eV are markedly increased after etching by CF4/H2 plasma of 10% dilution by H2, the yield for photons below ~5eV are clearly reduced for the case of 5%, which is almost the same with as grown-Si layer. This result implies that, flat Si-nanosheet without defect formation is confirmed by using the CF4/H2 plasma etching with 5% dilution by H2.

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References

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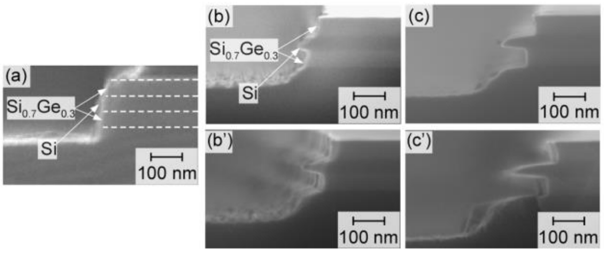

Fig. 1. Cross-sectional SEM images taken after (a) vertical etching with 13% H_2 diluted CF_4 plasma subsequent lateral etching with (b, b') 10%, and (c, c') 5% H_2 diluted CF_4 plasma for (b, c) 10, and (b', c') 20 min.

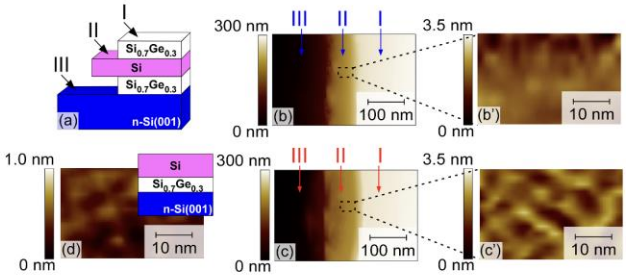

Fig. 2. (a) Schematic illustration of the sample after lateral etching, and AFM topographic images taken after lateral etching with (b, b') 10%, and (c, c') 5% H_2 diluted CF_4 plasma. (d) Schematic illustration and AFM topographic image of the Si layer epitaxially grown on $Si_{0.7}Ge_{0.3}$/n-Si(001) are also shown as a reference.

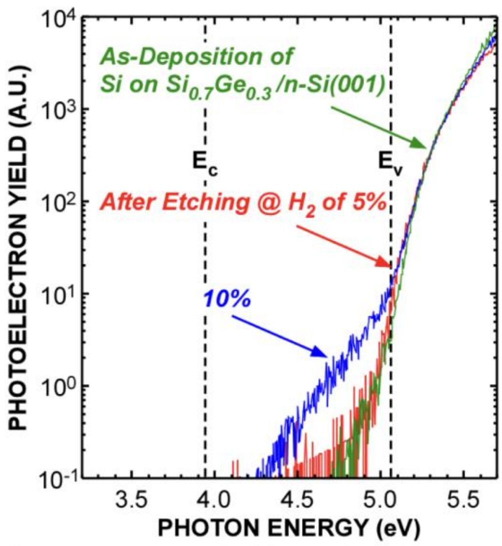

Fig. 3. PYS spectra of Si layer epitaxially grown on $Si_{0.7}Ge_{0.3}$/n-Si(001) and Si layer appeared by etching of the $Si_{0.7}Ge_{0.3}$ cap layer from $Si_{0.7}Ge_{0.3}$/Si/$Si_{0.7}Ge_{0.3}$ stacked using the CF_4/H_2 plasma.

Figure 1