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Germanium Layer Transfer with Epitaxial Lift-off Technique

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1. Introduction

Recently Germanium (Ge) has been investigated as a potential material platform not only for high performance CMOS but also for optoelectronic devices and high-efficiency solar cells. Meanwhile, Ge has nearly the identical lattice constant to GaAs, AlAs, and $Al_xGa_{1-x}As$ alloys in which epitaxial lift-off (ELO) processes have been demonstrated by sacrificially etching an AlAs layer in HF solution [1, 2]. Therefore, with the proper epitaxy, ELO, and a layer transfer for Ge layer, heterogeneous integrations of Ge layers with disparate materials systems can be realized because Ge is chemically resistant to HF solutions [3]. Figure 1 is a schematic flow of ELO process for Ge layer. First of all, a crystal Ge layer is epitaxially grown on GaAs or Ge substrate with an AlAs splitting layer. Then, the epitaxial Ge/AlAs/GaAs(Ge) heterostructure bonds with an arbitrary host substrate, such as Si, glass or plastic substrates. By splitting at AlAs layer with HF solvent, epitaxial Ge layer transfers on host substrates. Combined with novel epitaxy process and substrate bonding, ELO technique for Ge layers has a high potential to elaborate Ge-based engineered substrates as well as devices in a relatively cost effective manner.

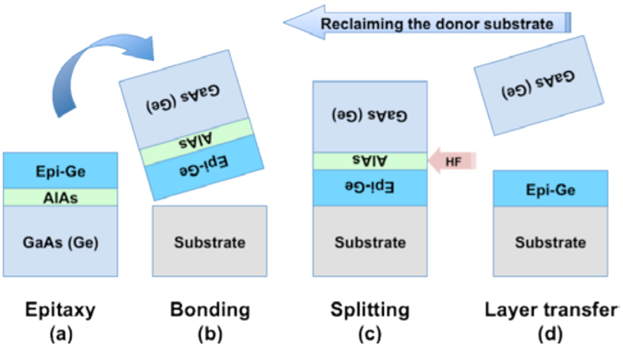

Figure 1. A schematic flow of the epitaxial lift-off (ELO) process of Ge layer. (a) Epitaxial Ge layer on GaAs (Ge) substrates with AlAs sacrificial layer. (b) Bonding with an arbitrary host substrate (c) Splitting at AlAs layer with HF solvent and (d) Epitaxial Ge layer transferred on host substrates.

2. Epitaxial lift-off (ELO) of Ge layer

As ELO substrate for epitaxial Ge layer, we prepared Ge (4.8um)/AlAs(150nm)/GaAs substrates as shown in Fig. 2. All epitaxial layer structures were grown by low pressure

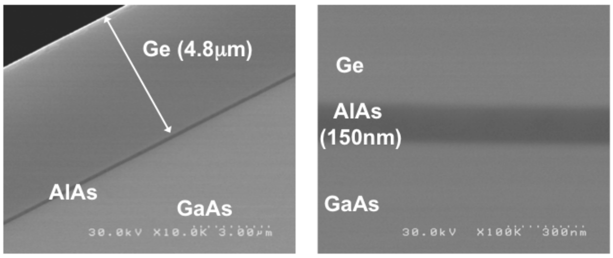

Figure 2. SEM images of epitaxial Ge/AlAs/GaAs heterostructure. The thicknesses of epitaxial Ge layer and AlAs sacrificial layer are 4.8μm and 150nm, respectively.

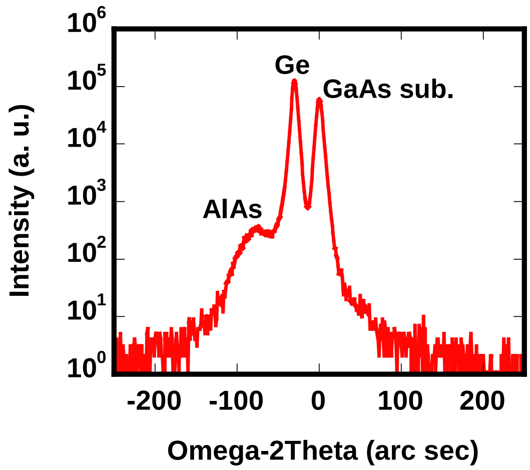

Figure 3. The measured XRD rocking curve from (004) refraction of the epitaxially grown Ge/AlAs layers on GaAs substrate.

CVD. Figure 3 presents the measured XRD rocking curve from (004) refraction of the fabricated Ge/AlAs/GaAs heterostructure. The rocking curve indicates three significant peaks attributed to GaAs substrate, Ge layer and AlAs layer. The linewidth of the Ge peak on AlAs/GaAs is 25.0 arc sec. It is confirmed that the epitaxial Ge layer on AlAs/GeAs has a quite high crystalline quality.

Using this Ge/AlAs/GaAs heterostructures, we lifted off epitaxial Ge layers from die-level (10 x10mm^2) to device size (<100x100μm^2). Needless to say, such thin Ge layers are very fragile and must be supported at all times. The initial mechanical supports during and after ELO came from the wax or arbitrary substrates with adhesive. The Ge/AlAs/GaAs substrates were then immersed into a 49% HF solution at room temperature. The HF solution laterally etched the AlAs layer, allowing for the release of the bonded Ge layer from GaAs donor substrate. Eventually Ge layers floated on the solution surface because their hydrophobic surface and the buoyant force of the wax (Fig. 4 (a)). This self-peering of epitaxial Ge layers with die–level size of 10x10 mm^2 was achieved approximately 5 hours. Figure 4 (b) is the photograph of the ELO Ge layer bonded to the flexible plastic sheet with adhesive and donor GaAs substrate. Comparing the GaAs donor substrate, it is clear that die-level Ge layer transfer is carried out successfully.

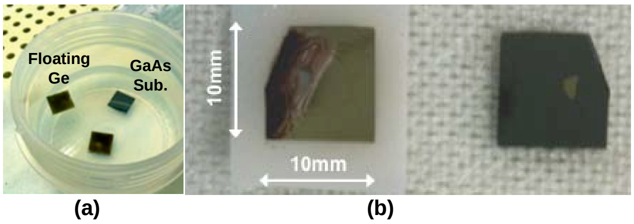

Figure 4. The photographs of (a) the floating Ge layer and GaAs donor substrate in HF solution and (b) the ELO Ge layer with die-level size (10x10mm^2) on the flexible plastic sheet with adhesive (left) and initial GaAs donor substrate (right).

In order to demonstrate ELO Ge layer with device size (<100x100μm^2), we fabricated the patterned Ge layer as shown in Fig. 5 (a). Ge layer was patterned by RIE and 150nm-thick AlAs layer etched subsequently only by pure water. Then the patterned Ge layer was bonded to Si substrate. Here we used the spin-coated polyimide as an adhesive on Si substrate. ELO completed in less than 10min that is short enough for practical use. Figure 4 (b) is the photograph of the transferred Ge Hall pattern on Si. Hall pattern with 50x50um^2 area are clearly transferred with no clack.

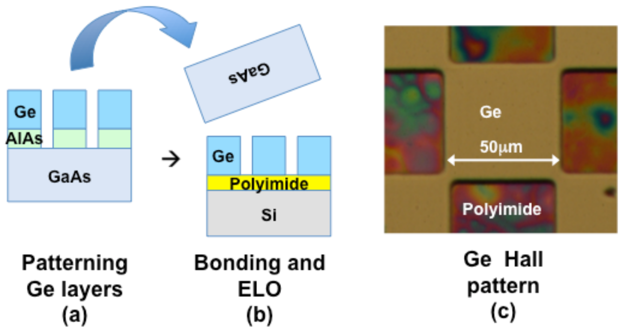

Figure 5. The schematic flow of the patterned Ge layer ELO process in device size (<100x100μm^2) ((a) and (b)). The photograph of the transferred Ge Hall pattern on Si with polyimide as an adhesive (c).

3. Ge device layer transfer by ELO

ELO technique can be utilized not only for just single crystal Ge layer, but also for Ge-base device layer transfers. To demonstrate the feasibility of Ge device layer transfer, we fabricated Ge-based electronic devices including pMOSFETs, diodes, resistors, etc on Ge/AlAs/GaAs substrate [4]. After bonding to Si substrate and ELO process, Ge device layer was transferred on glass using van der Waals bonding (Fig. 6 (a)-(d)). Figure 7 is I_{DS}–V_G characteristics of Ge pMOSFET on glass (L_G = 4μm). Ge device after transfer on glass exhibits excellent transistor behavior, revealing the device level quality of ELO Ge layer.

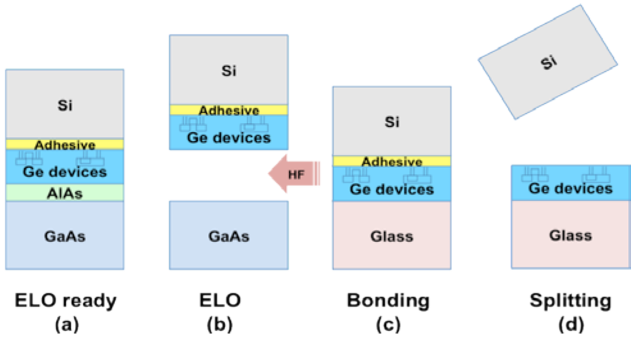

Figure 6. The process flow of Ge device layer transfer with ELO technique.

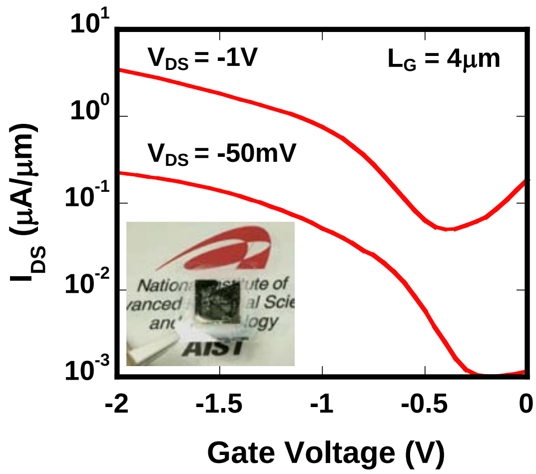

Figure 7. I_{DS}–V_G characteristics of Ge pMOSFET on glass (L_G = 4μm). The inset is the photograph of Ge device layer on glass including pMOSFETs, diodes, resistors, etc.

4. Conclusions

To obtain the high quality Ge layers on arbitrary host substrates, ELO technique is implemented for Ge/AlAs/GaAs heteroepitaxial structures in which AlAs layer acts as the splitting layer. We have successfully demonstrated Ge layer transfer from die-level size (10x10mm^2) to device size (<100x100μm^2) on arbitrary host substrates. These results reveal that Ge layer transfer with ELO technique offers a flexible opportunity for Ge-based material integration.

Acknowledgements

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References

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