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Selective Liquid-Phase Oxidation of InGaAs and Application to Metal–Oxide- Semiconductor InAlAs/InGaAs Metamorphic HEMT Without Gate Recess

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A selective, low cost, low temperature (30–70 ° C), liquid phase oxidation of InGaAs using metal or photoresist as the mask has been proposed, and the oxide film composition and some process issues are also evaluated. Finally, the application of InAlAs/InGaAs MOS-MHEMT without gate recess has also been demonstrated. Without gate recessing, the gate oxide is obtained directly by oxidizing the InGaAs capping layer in a growth solution. As compared to its counterpart MHEMT, the MOS-MHEMT makes the proposed low-temperature and selective liquid-phase oxidation suitable for high power applications. Also, the InAlAs/InGaAs MOS-MHEMT samples exhibit the advantages of growing sidewall passivation and native gate oxide at the same time.
Recently, a simple and selective liquid-phase oxidation on GaAs-based materials operated at near-room-temperature (30–70°C) has been proposed and investigated. Based on this, various materials have been used to grow native oxides, such as Si, InP, AlGaAs, InGaP, InGaAs, InAlAs, and so on. Liquid-phase oxidation takes place by in-diffusion of oxygen at the oxide-semiconductor interface, such that a fresh interface region can be achieved due to the original semiconductor surface contaminants ending up on the oxide surface. With the technique, the growth of the native oxide film can be controlled well with good reproducibility at low temperatures. Additionally, using the electroless technique, neither vacuum nor gas condensation equipment nor assisting energy source is needed. Consequently, the liquid-phase oxidation not only exhibits the lowest process temperatures and system complexity but also provides oxides with a comparable and even superior quality.

The selective oxidation process is schematically illustrated in Fig. 1. First, the PR was coated on the $In_{0.53}Ga_{0.47}As$ layer, the pattern of which was designed by the photolithographic processes. Then, the sample was transferred into the growth solution for oxidation. An oxide layer can be grown only on a bare InGaAs surface that is not covered by PR. After removing the PR using acetone, the final selectively oxidized structure can be obtained. The oxide film can also be etched using diluted HF solution, and the InGaAs seems to be consumed due to the loss of oxide species according to the scanning electron microscopy (SEM) image. As shown in Fig. 2, a high contract between InGaAs and oxidized InGaAs area on the top surface can also be seen by the SEM image.

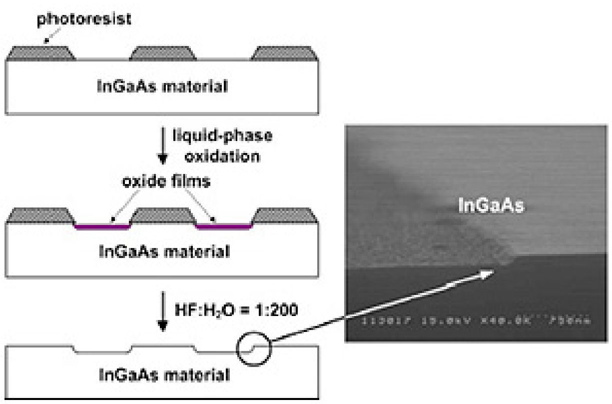


Fig. 1. The schematic cross-sectional view of the proposed selective oxidation procedure on $In_{0.53}Ga_{0.47}As$ material using PR films masks.

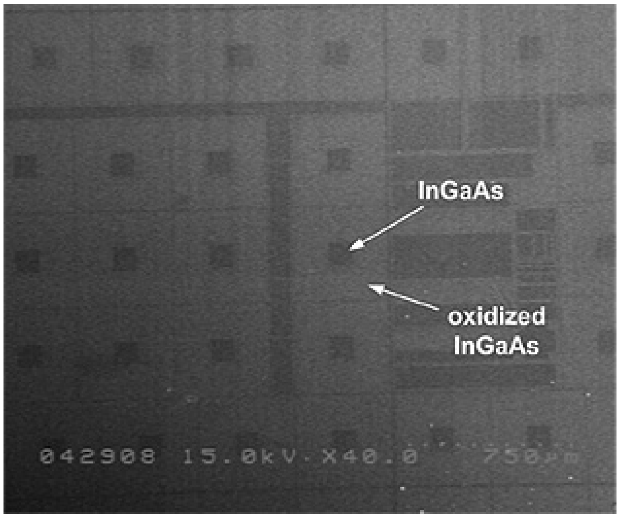


Fig. 2. Example of top view by SEM image. The high contrast of the $In_{0.53}Ga_{0.47}As$ surface and oxide area can be seen.

For $In_{0.52}Al_{0.48}As$ / $In_{0.53}Ga_{0.47}As$ MOS-MHEMT application, the MHEMT epitaxial structure was grown by metallorganic chemical vapor deposition on a semi-insulating GaAs substrate as shown in Fig. 3(a). The measured room-temperature Hall mobility and sheet carrier concentration were 7000 cm^2/V s and 2 $x10^{12}$ cm^{-2}, respectively. The fabrication started with mesa isolation by wet etching down to the buffer layer. The ohmic contacts of the Au/Ge/Ni metal were deposited by evaporation and were then patterned by lift-off processes, followed by rapid thermal annealing (RTA). Then, applying the liquid-phase oxidation procedure without gate recess, the wafer was directly immersed into the growth solution to generate an $In_{0.53}Ga_{0.47}As$ gate oxide at 50 ° C for a period of time (e.g., 1 h). After this, the oxide films selectively and simultaneously selfaligned to passivate the surface and the sidewalls as shown in Fig. 3(b). Utilizing the liquid-phase oxidation, the proposed application used the Au/Ge/Ni metal as a mask for selective oxide growth on InGaAs. Finally, the gate metal Au was deposited. The gate dimension and the drain-to-source spacing are 0.65 x 200 μm^2 and 3 μm, respectively. For $In_{0.53}Ga_{0.47}As$ material, the oxidation rate is about 10–15 nm/h in the growth solution, with initial pH = 5.0 at 50 ° C without any pH

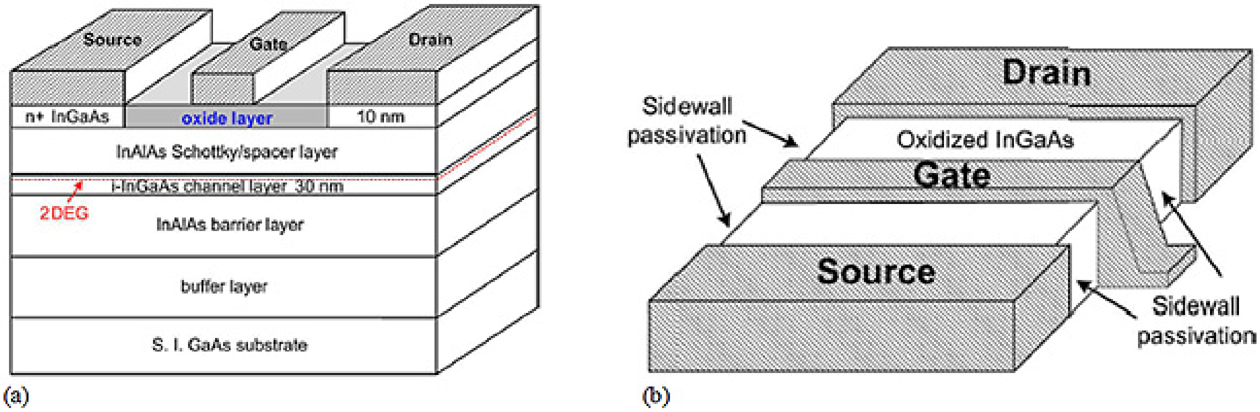
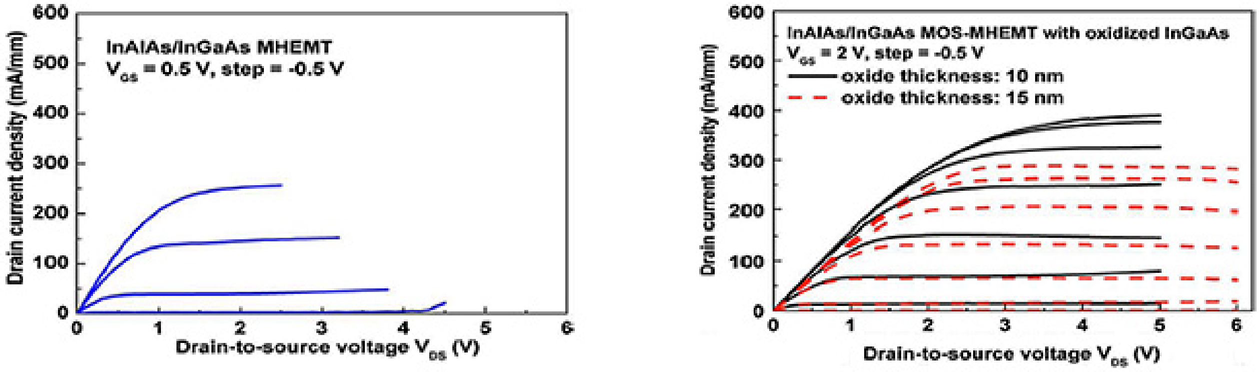


Fig. 3. The schematic cross-sectional views of (a) the InAlAs/InGaAs MOS-MHEMT structure and (b) the mesa sidewall passivation

control, which is lower than that of $In_{0.15}Ga_{0.85}As$ material (15–20 nm/h). The thickness of the as-grown oxide film is ~42 nm evaluated using an ellipsometer. A heterogeneous composition of the as-grown $In_{0.15}Ga_{0.85}As$ oxide was found in the XPS depth profile. According to the XPS signals of In-3d, Ga-3d and As-3d core level indicate that the oxide films are composed of the compound of In_2O_3, Ga_2O_3, and As_2O_3 .



(a) (b)

Fig. 4. I_{DS}-V_{DS} characteristics of (a) reference MHEMT and (b) MOS-MHEMTs with 10 and 15 nm thick oxides.

Figures 4(a) and (b) show the drain current density I_{DS} vs the drain-to-source voltage V_{DS} of reference MHEMT and MOS-MHEMTs, respectively. Besides, good pinch-off and saturation characteristics are obtained. Due to the higher energy barriers at the gate interface, the MOS-MHEMT can be operated at higher V_{DS} and gate-to-source voltage V_{GS} than those of the counterpart MHEMT, which can enhance the current driving capability; this is promising for realizing high-power device applications. While the conventional Schottky-gate MHEMT may suffer from lower gate-swing voltage and lower breakdown voltage, which may limit the applications of the device.

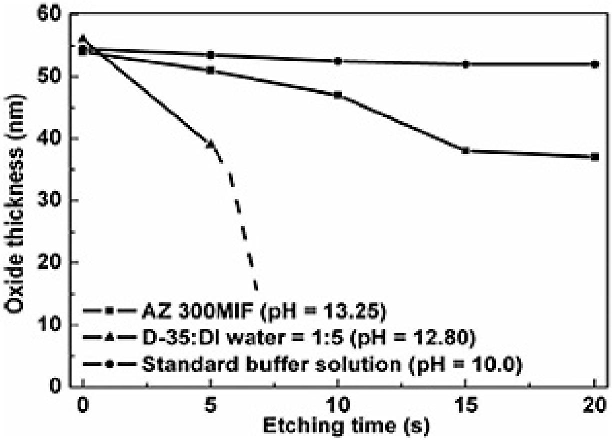


Fig. 5. A plot for the thickness of the as-grown $In_{0.15}Ga_{0.85}As$ oxide vs etching time in alkaline solutions for different pH values.

For device fabrication, the photolithographic process is necessary; consequently, the as-grown oxide has the opportunity to expose to the developer directly. In order to study the etching phenomena of the oxide in chemical solutions such as the developer, experiments on immersing the oxide into chemical solutions for a certain period and measuring the variation of its thickness by the ellipsometer were performed. Figure 5 shows a plot for the thickness of the as-grown $In_{0.15}Ga_{0.85}As$ oxide without PR as a function of etching time in the diluted D-35 developer (pH 12.80), the AZ 300MIF developer (pH 13.25), and the standard buffer solution (pH 10.0). The basis of the AZ 300MIF developer is tetramethylammonium hydroxide (TMAH), and the basis of the D-35 developer is NaOH. As shown in the figure, the oxide without PR starts to be etched in the diluted D-35 developer of pH 12.80 for 5 s.

In summary, Low-temperature (30–70 ° C) selective liquid-phase oxidation of InGaAs using photoresist or metal as the mask is proposed, and the oxide film composition is evaluated. Further, the application of the InAlAs/InGaAs metal-oxide-semiconductor metamorphic high-electron-mobility transistor (MOS-MHEMT) is also demonstrated. Without gate recessing, the gate oxide is obtained directly by oxidizing the InGaAs capping layer in a growth solution. In comparison, the InAlAs/InGaAs MOS-MHEMT is a good candidate for high-power applications.