$Al_{0.3}Ga_{0.7}As/GaAs$ 다층구조의 레이저 직접 건식에칭

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Laser Direct Dry Etching for $Al_{0.3}Ga_{0.7}As/GaAs$ Multi-layer Structures

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Abstract

Laser direct dry etching is a new technique in semiconductor processing which has a lot of advantage, including decrease of etching-induced damage, maskless, photoresistless, and high selectivity. This study presents characteristics of a laser direct dry etching for $Al_{0.3}Ga_{0.7}As/GaAs$ multi-layer structures for the first time. In this study, we were able to obtain the unusual etching profiles. The cross sectional analysis of etched groove was performed for reaction characteristics and their applications.

1. Introduction

Conventional multistep processing, represented by lithographic technology, is not appropriate to the optoelectronic device fabrication. Laser-induced microchemical etching provides etching rates which are three to four orders of magnitude higher than those produced with other processings[1]. The laser etching process yields a high-aspect ratio feature required for fabrication of advance optoelectronic and micromechanical devices. Recently, a series of laser microchemical techniques has been developed for restructuring a semicustom integrated circuit under test[2]. Laser-induced microchemical etching also offer an attractive method as primary patterning techniques for the emerging field of microelectromechanical systems[3]. In our previous studies, laser-induced dry etching of GaAs in CCl_2F_2 was performed to obtain trench structures with high-aspect ratio[4]. The changes of stoichiometry in etched layers were also investigated. The damage owing to this processing is much lower than that caused by other processings, such as plasma, ion beam, electron beam etching[5]. However, the use of CCl_2F_2 gas has been restricted because of environmental problems. This study represents the initial use of KIST pioneered non-ozone layer destructive CFC alternatives as replacements of CCl_2F_2 for the environmental harmfulness. Etching characteristics of GaAs using $C_2H_2F_4$ gas have been compared with those using CCl_2F_2 gas. Chemical compositions of etching reaction products and the thickness of a nonstoichiometric layer on the etched surface were measured by AES with an argon sputtering system.

2. Experimental procedures

$Al_{0.3}Ga_{0.7}As/GaAs$ multi-layer structures were grown by conventional MOCVD on a (100) semi-insulating GaAs substrate. A GaAs layer was inserted between AlGaAs layers and the top layer was capped with GaAs. The AlAs mole fraction was fixed at 0.3. A sample was mounted on a vacuum chamber. The chamber was fixed on an electrically controlled X-Y-Z stage and evacuated by a rotary pump down to 10^{-3} Torr. The reaction gases of CCl_2F_2 and $C_2H_2F_4$ were introduced into the chamber through a needle valve at a pressure ranging from 60 to 1100 Torr. The multi-line of argon ion laser was focused by a microscope object lens (NA=0.4) down to a spot diameter 1.2 μm (at 1/e intensity) on the sample surface. Laser beam power(power density) on the sample surface were varied from 170 mW(15.0 MW/cm^2) to 250 mW(22.1 MW/cm^2). The laser beam was scanned over the sample by moving the stage with a speed ranging from 8 μm/sec to 80 μm/sec. Figure 1 shows a schematic diagram of a laser direct dry etching system. Etched profiles, such as depth and width, were observed by scanning electron microscope (SEM). The chemical composition of the reaction products, which were deposited on the etched area, was measured by Auger electron spectroscopy (AES). The simulation of temperature rising of the samples was worked by computational method for etching mechanism[6-9].

3. Results and discussion

In order to achieve optimum conditions for fine etching profile, we carried out the experiments with varying a gas pressure, beam scan speed, and laser power. The best conditions are obtained at the gas pressure of 760 Torr and the scan speed of 8 - 13 μm/sec. We were able to obtain the unusual etching profiles. Photograph 1 shows the etched groove in AlGaAs/GaAs multi-layer structures by a laser power of 190 mW, a scan speed of 13 μm/sec, and a CCl_2F_2 pressure of 760 Torr. Phot. 1 shows that the etched width of the GaAs/AlGaAs interface is larger than that of AlGaAs/GaAs interface. This result is caused by the differences of thermal conductivity, absorption coefficient, and melting point between GaAs and AlGaAs epi-layers. The thermal conductivity of GaAs(0.44 W/cmK at T=300 K) is larger than that of $Al_{0.3}Ga_{0.7}As$(0.106 W/cmK at T=300 K)[10]. The optical absorption coefficient of GaAs(111.74×10^3/cm at λ=500 nm) is larger than that of $Al_{0.3}Ga_{0.7}As$(77.3×10^3/cm at λ=500 nm)[11]. The melting points of GaAs and AlGaAs are 1513 K and 1544 K, respectively. The good thermal confinement at GaAs/AlGaAs interface made the etched width of the GaAs layer larger than that of AlGaAs. Because the thermal confinement is more good in AlGaAs than in GaAs and the melting point of AlGaAs is higher than that of GaAs. Figure 2 shows the temperature rising of the samples(GaAs and AlGaAs) was worked by computational method for analyzing the etching mechanism. In Fig. 2, before arriving at the melting points of GaAs and AlGaAs, temperatures of the surfaces are exponentially increased with increasing of the laser beam power. Particularly, in the AlGaAs case, the temperature rise abruptly around the melting point. These difference of the surface temperatures between GaAs and AlGaAs occurred, because the optical absorption coefficient and thermal conductivity of AlGaAs are lower than those of GaAs. Thus, the good thermal confinement at GaAs/AlGaAs interface made the etched width of the GaAs layer larger than that of AlGaAs. We will discuss that the etched width is able to be controlled by varying of the AlAs mole fraction and thicknesses of epi-layers.

4. Summary

This study presents the characteristics of a laser direct dry etching for $Al_{0.3}Ga_{0.7}As$/GaAs multi-layer structures for the first time. This experiment shows that the good thermal confinement at GaAs/AlGaAs interface results in expansion of the etched width of GaAs epi-layer. Thus, we were able to obtain the unusual etching profiles. It is expected that this study can be applied to micromechanical device, optoelectronic device, waveguide, and isolation.

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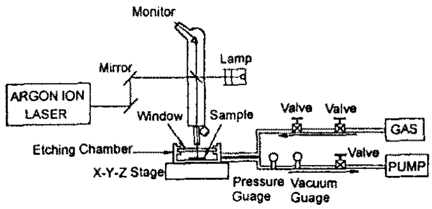
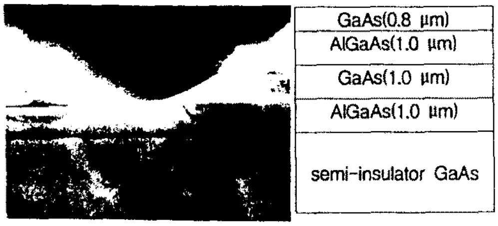


Fig. 1. A schematic diagram of a laser direct dry etching system.



Phot. 1. SEM cross sectional view of the etched groove obtained by a laser power of 230 mW, a scan speed of 13 μm/sec, and a CCl_2F_2 pressure of 760 Torr.

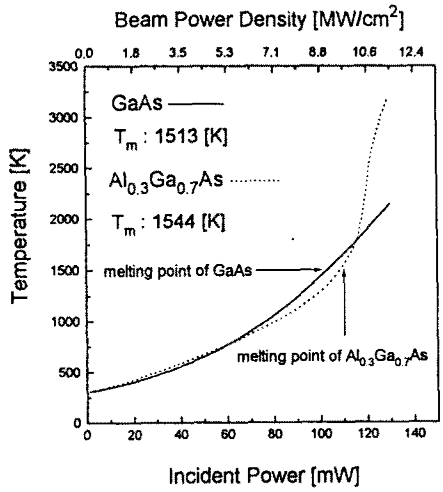


Fig. 2. The temperature rising of the samples(GaAs and AlGaAs) was worked by computational method.