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The Electrical Effect of AlGaAs Barrier at the Heterointerface of Selectively Doped GaAs/n-AlGaAs Heterostructure

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The effect of an interface potential barrier layer on the electrical properties of a selectively doped GaAs/N-AlGaAs heterostructure has been investigated. By reducing Al content in the N-$Al_xGa_{1-x}As$ layer (x = 0.15, 0.2) and introducing a 60-Å-thick $Al_yGa_{1-y}As$ interface barrier layer (y = 0.3), high mobility of two dimentional electron gas, much reduced persistent photoconductivity, and low resistivity of ohmic contact were achieved in selectively doped GaAs/N-$Al_xGa_{1-x}As$ heterostructures grown by MBE.

1. Introduction

There has been an increasing number of reports on selectively doped (SD) GaAs/N-AlGaAs heterostructures and their applications to HEMTs[1,2]. Most of them relate to a simple heterostructure, which compose of an undoped GaAs layer and a Si-doped $Al_xGa_{1-x}As$ (x = 0.3) layer. There are, however, some problems such as the large amout of persistent photoconductivity, high resistivity of the ohmic contacts in the SD GaAs/N-AlGaAs heterostructure. In this paper, we investigated a SD GaAs/N-AlGaAs heterostructure with an interface barrier layer in order to improve the electrical properties and light sensitivity of the heterostructure.

2. Electrical Properties

A schematic diagram of SD GaAs/N-AlGaAs heterostructure with an interface barrier layer is shown in Fig.1. It consists of a Si-doped N-$Al_xGa_{1-x}As$ layer (500-Å-thick, Si-doping concentration N_d = $2x10^{18}$ cm^{-3}, x = 0.15, 0.2, 0.3), a 60-Å-thick, undoped $Al_yGa_{1-y}As$ (y = 0.3, 0.4, 0.45) interface barrier layer (which works also as a spacer-layer) and an undoped GaAs layer (0.6-μm-thick). Four different GaAs/N-AlGaAs heterostructurs with an interface barrier structure, as listed in Table 1, were grown on semi-insulating GaAs substrates at a temperature of 680°C by MBE.

2DEG mobility and sheet electron concentration at 77K of SD GaAs/N-AlGaAs heterostructures with an interface barrier layer are plotted as a function of AlAs mole fraction (x) in the N-$Al_xGa_{1-x}As$ layer, together with those of conven--tional SD GaAs/N-AlGaAs heterostructures which have not an interface barrier layer (Fig.2). The result obtained previous work[3] is also shown in the figure. Almost same results were obtained for the 2DEG concentration in both the conventional SD GaAs/N-$Al_xGa_{1-x}As$ heterostructures (x = 0.15, 0.2, 0.3, N_d = $2x10^{18}cm^{-3}$, thickness of an undoped spacer-layer Δt = 60Å) and the interface barrier heterostructures. 2DEG mobility of a conventional

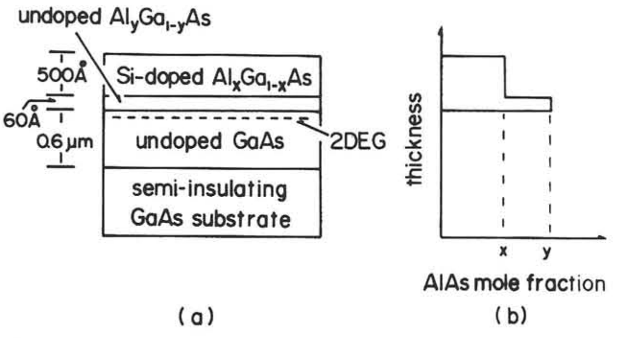

Fig.1 Schematic diagram of a selectively doped GaAs/N-$Al_xGa_{1-x}As$ heterostructure with a interface barrier of $Al_yGa_{1-y}As$ (a) and its composition profile (b). The values of x and y are listed in Table 1 also with electron mobility and sheet electron concentration.

SD GaAs/N-AlGaAS heterostructure decreased significantly with decreasing AlAs mole fraction as previously reported. It became as low as 2.0×10^4 cm^2/Vs at x = 0.15. It was speculated that this is mainly due to penetration of 2DEG wave function into the AlGaAs region because of low potential barrier hight at the heterojunction interface[3]. This penetration effect is expected to be much reduced by introducing high potential barrier at the heterojunction interface. In the case of the interface barrier heterostructures (y = 0.3), 2DEG mobility was much improved especially for x = 0.15 and 0.2, as is expected. This result proved the speculation of the previous paper that the

Table 1 Composition of SD GaAs/N-$Al_xGa_{1-x}As$ heterostructures with an interface barrier of 60Å-thick $Al_yGa_{1-y}As$ layer, and their electron mobility and sheet electron concentration at 77K.

sample	x	y	mobility (cm^2/Vs)	sheet concent. (cm^{-2})
#1	0.15	0.3	77,000	4.4×10^{11}
#2	0.2	0.3	102,000	5.6×10^{11}
#3	0.3	0.4	110,000	5.7×10^{11}
#4	0.3	0.45	109,000	5.9×10^{11}

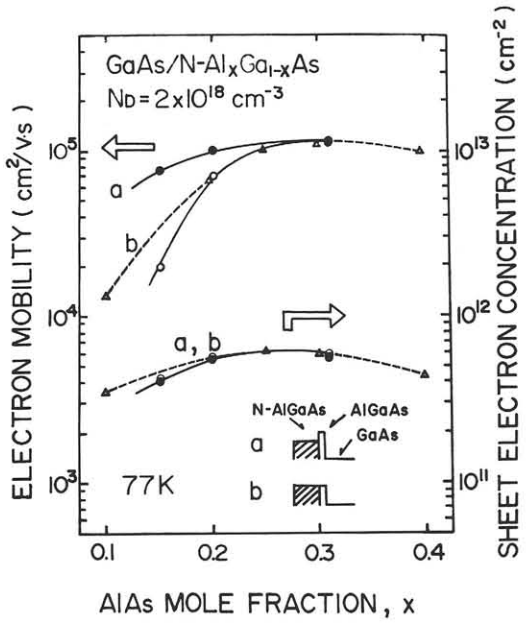

Fig.2 2DEG mobility and sheet electron concentration in SD GaAs/N-$Al_xGa_{1-x}As$ heterostructure with (a) and without (b) an interface barrier at 77K as a function of AlAs mole fraction of an N-$Al_xGa_{1-x}As$ layer. The result of previous work is also shown by triangle.

penetration of 2DEG wavefunction into the AlGaAs region result in reduced 2DEG mobility in SD GaAs/N-AlGaAs with small value of x less than 0.2. For an SD GaAs/N-$Al_xGa_{1-x}As$ heterostructrure (x = 0.3), the effect of an interface barrier layer (y = 0.4 and 0.45) on 2DEG mobility is not so clear. This indicates that the penetration of 2DEG wavefunction into AlGaAs region is much reduced and it is no longer a dominant factor for limiting 2DEG mobility when the potential barrier hight is larger than about 0.3 eV.

Figure 3 shows the temperature dependence of electron mobility and sheet electron concentration of the SD GaAs/N-$Al_xGa_{1-x}As$ hetero-structures (x = 0.15) with and without an interface barrier layer (y = 0.3), and a conventional SD GaAs/N-$Al_xGa_{1-x}As$ heterostructure (x = 0.3). The mobility for the heterostructure of x = 0.15 without barrier was not improved significantly when the temperature was decreased. The sample with the barrier, however, exhibited much improved electron mobility at low temperatures (78,000 cm^2/Vs at 77K, 130,000 cm^2/Vs at 4K), and the over-all trend is very similar to that of the conventional SD GaAs/ N-$Al_xGa_{1-x}As$ heterostructure with x = 0.3. Therefore, the interface barrier layer (y = 0.3) at the hetero-

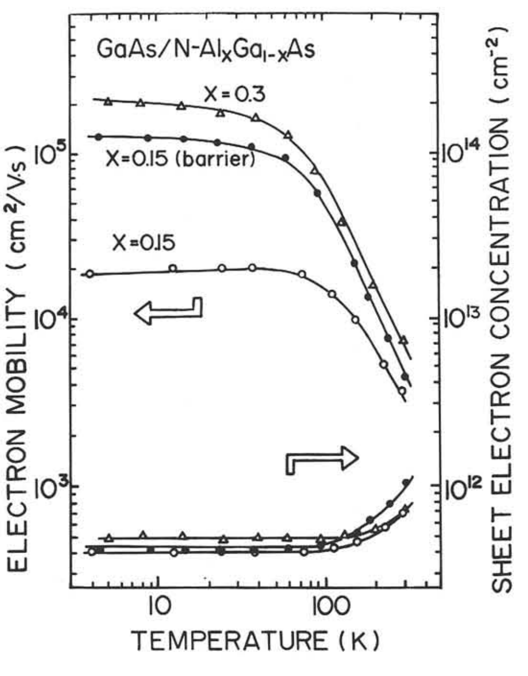

Fig.3 Temperature dependence of electron mobility and sheet electron concentration in SD GaAs/N-$Al_xGa_{1-x}As$ heterostructures (x=0.15) with and without an interface barrier, and a conventional heterostructure (x=0.3).

interface was found to be very effective in obatining high 2DEG mobility for SD GaAs/N-AlGaAs heterostructure with the low AlAs mole fraction in the N-$Al_xGa_{1-x}As$ layer (x = 0.15, 0.2).

For device applications, a low AlAs mole fraction is prefered to reduce the ohmic resistance of the HEMT. Resistivity of ohmic contacts can be reduced about one order of magnitude by decreasing x from 0.3 to 0.2 at 77K in SD GaAs/N-$Al_xGa_{1-x}As$ heterostructures. Therefore, SD GaAs/N-$Al_xGa_{1-x}As$ heterostructure ($x \lesssim 0.2$) with the interface barrier layer is promising to realize a low-ohmic-resistance HEMT.

3. Persistent Photoconduction

In this section, we will describe the photoconduction of the SD GaAs/N-$Al_xGa_{1-x}As$ heterostructure. It is well known that the sheet concentration of 2DEG of SD GaAs/N-$Al_xGa_{1-x}As$ heterostructure ($x \doteqdot 0.3$) increases considerably at low temperature (< 100K) by exposure to light and increased 2DEG concentration persists even after the light is turned off. This persistent photoconductivity (PPC) has attracted much interest because it can have a profound effect on HEMT stability at low temperature. The PPC in the heterostructure is considered to be due to the so-called DX centers in the N-Al_xGa_{1-x} As layer (x = 0.3)[4]. A DX center is assumed to be a donor-vacancr complex associated with large lattice relaxation[5] and its concentration is proportional to the Si donor concentration[6]. Therefore, it seems to be very difficult to eliminate the PPC in the conventional SD GaAs/N-$Al_xGa_{1-x}As$ heterostructure (x = 0.3). We achieved low PPC in SD GaAs/N-$Al_xGa_{1-x}As$ heterostructure by reducing AlAs mole fraction in the Si-doped N-$Al_xGa_{1-x}As$ layer.

Figure 4 shows the amount of persistent increase of 2DEG concentration, Δn_s, for SD GaAs/N-$Al_xGa_{1-x}As$ heterostructures after turning off the white light as a function of the AlAs mole fraction in the N-$Al_xGa_{1-x}As$ layer. The values of Δn_s were characterized by Van der Pauw-Hall measurement after a few mimutes of turning off white light. Open circles (solid circles) correspond to the SD GaAs/N-AlGaAs heterostructures with (without) an interface barrier layer. The amount of PPC depended heavily on the AlAs mole fraction in the N-$Al_xGa_{1-x}As$ layer and became very small for x = 0.2 and 0.15. For the same value of x, the introduction of the interface barrierdid not change the amount of PPC. Therefore, the SD GaAs/N-$Al_xGa_{1-x}As$ ($x \lesssim 0.2$) heterostructure with an interface barrier was found to be suitable for the preparation of 2DEG of high mobility and low PPC.

The dependence of PPC on the wavelength of light was measured. Fig.5 shows the persistent increase of current when the wavelength of light

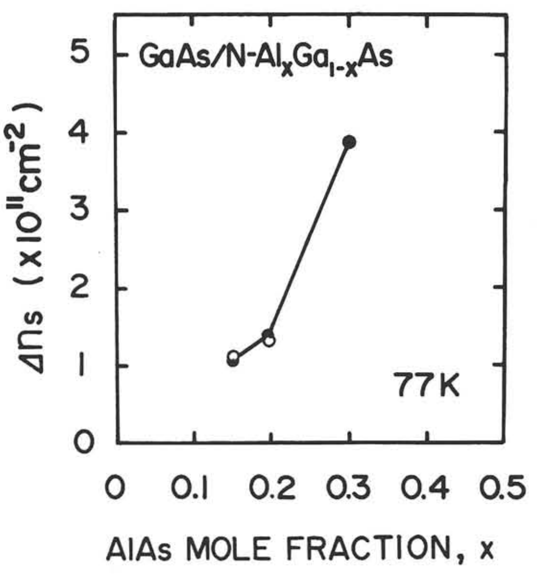

Fig.4 The amount of persistent increase of 2DEG concentration, Δn_s, in SD GaAs/N-$Al_xGa_{1-x}As$ heterostructures with (o) and without an interface barrier layer (•) after exposure to white light at 77K as a function of AlAs molefraction in the N-$Al_xGa_{1-x}As$ layer.

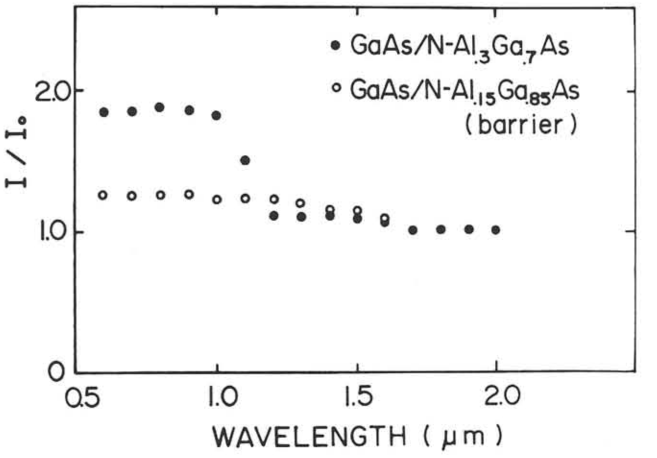

Fig. 5 Wavelength dependence of persistent increase of current, I/I_0 (normalized by the value of dark current), in SD GaAs/N-$Al_xGa_{1-x}As$ heterostructures.

was scanned from 2.0 μm to 0.5 μm at 77K. It is normalized by the value of dark current. In the conventional SD GaAs/N-$Al_xGa_{1-x}As$ heterostructure (x = 0.3), the current increased considerably at around 1.1 μm, which is consistent with the photo-ionization energy of DX center. For the SD GaAs/N-$Al_xGa_{1-x}As$ heterostructure (x =0.15) with an interface barrier layer, however, the current increase in this region was very small with a gradual increase in the region 1.1 to 1.5 μm. Therefore, it is considerd that there exist small amount of DX centers in the N-$AL_xGa_{1-x}As$ layer (x = 0.15).

4. Conclusion

We obtained high mobility 2DEG in the SD GaAs/N-$Al_xGa_{1-x}As$ heterostructure for low AlAs mole fraction of N-$Al_xGa_{1-x}As$ layer (x = 0.15, 0.2) by introducing a 60-Å-thick $Al_yGa_{1-y}As$ interface barrier layer (y = 0.3). This technique, which is easily implemented by MBE, provides a promising method to reduce PPC and ohmic resistance in SD GaAs/N-AlGaAs heterostructures.

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