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# New Self-Aligned Gate Material; $LaB_6$ for GaAs-IC

Tatsuo Yokotsuka, Yoko Uchida, Keisuke L. I. Kobayashi

Tadashi Narusawa and Hisao Nakashima

Optoelectronics Joint Research Laboratory

1333 Kamikodanaka, Nakahara-ku, Kawasaki 211, Japan

We propose $LaB_6$ as a new self-aligned gate material and investigate the Schottky interface of $LaB_6$/GaAs(001) using XPS, RBS and electrical characteristics measurements. The ideality factor of 1.09 and the barrier height of 0.773 eV are obtained for the Schottky diode annealed at 850°C. Excellent thermal stability is observed by XPS and RBS. These results indicate that $LaB_6$ is promising for GaAs-IC.

## §1 Introduction

Since the gate material determines the characteristics of GaAs MESFET devices, its choice is the most important subject. In the self-alignment technology, which has been very successful for fabrication of high speed GaAs-IC's, high temperature annealing is mandatory for carrier activation. The drain and source regions of MESFET are made by ion-implantation using the gate material as the mask and subsequent annealing. This sophisticated technique makes it possible to form small sized gates and short channels. These features are neccesary for high speed IC to avoid high parasitic resistivity and drift capacitance.

In recent years, many high melting point materials for self-alignment gate material have been investigated, for example, tungsten[1], tungsten silicide[2], Ti-W silicide[3], and tungsten-nitride[4]. However, some problems still remain; i.e., careful control of the compound composition is required to obtain high thermal stability, and the electrical resistivity of these compound films is higher than that of pure metals.

In order to overcome these problems, we propose a novel gate material for GaAs-IC MESFET, that is lanthanum hexaboride ($LaB_6$), which has been used as electron emitters[5]. This material has superior properties as shown in Table 1. i) The heat of formation of $LaB_6$ is very high ( 112 Kcal/mol ) and even higher than

| | Crystal structure | Lattice constant (Å) | Melting point (°C) | Heat of formation Kcal/mol | Thermal expansion coefficient /°C | Electical resistivity $\Omega\cdot$cm |
|---|---|---|---|---|---|---|
| $LaB_6$ | Cubic | 4.15 | 2715 | 112 | $5.6\times10^{-6}$ | $8.9\times10^{-6}$ |
| $W_3Si_2$ | Tetragonal | a 9.645<br>c 4.969 | 2320 | --- | --- | --- |
| $WSi_2$ | Tetragonal | a 3.21<br>c 7.82 | 2120 | --- | 6.3-<br>9.0 | 16.0-<br>38.2 |
| W | Cubic | 3.16 | 3410 | --- | 4.5 | 5 |
| GaAs | Cubic | 5.64 | 1238 | 44 | 5.7 | --- |

TABLE 1 Electrical and thermal properties of gate materials.

that of GaAs ( 44Kcal/mol ). This comes from its crystal structure[5]; based on the three-dimensional boron frame-work which is constructed by strong covalent bonds and the lanthanum ion situated in the large space in the boron frameworks. This would impede any reaction between $LaB_6$ and GaAs. ii) The thermal expansion coefficient of $LaB_6$ is nearly equal to that of GaAs ( $5.6 \times 10^{-6}$ /°C for $LaB_6$ and $5.7 \times 10^{-6}$ /°C for GaAs ). Therefore, no stress would grow at the $LaB_6$/GaAs interface due to high temperature heat treatments. iii) The electrical conductivity as high as pure metals reduces the parastic resistivity. iv) Films of $LaB_6$ are obtained very easily by simple electron beam evaporation. The formation of $LaB_6$ films depends on the substrate temperature. The films grow amorphous at below 350°C and become crystalline at higher temperatures[6].

These good characteristics of the thermal-stability, the electrical conductivity and easy film formation support the $LaB_6$ is a novel candidate for the gate material of GaAs IC. In the present study, we examine the thermal stability and electrical characteristics of the Schottky interface between $LaB_6$ and GaAs by means of X-ray Photoemission Spectroscopy (XPS), Rutherford Backscattering (RBS), and I-V measurements.

## §2 Experimental

Clean GaAs(001) c-4x4 surfaces were grown by molecular beam epitaxy (MBE) and $LaB_6$ was deposited by $e^-$ gun from single crystal source. XPS measurements were performed with VG-ADES 400 system in the same ultra high vacuum system. RBS channeling spectra were taken in a seperate vacuum system using 4.5 MeV $He^+$ ion beam. I-V characteristics measurements were done with n-type ( $n=1 \times 10^{17}/cm^3$ ) GaAs wafers.
After $LaB_6$ was deposited onto the wafer by about 2000 Å thickness, electrodes were patterned by chemical etching using dilute $HNO_3$ solutions.

## §3 Results and Discussion

a) XPS

Figs. 1 and 2 show coverage dependences of XPS spectra, where $LaB_6$ was deposited on the

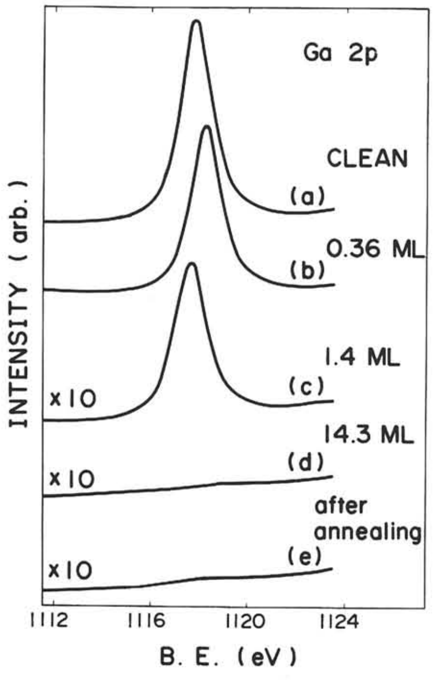


FIG. 1 Ga2p core level spectra at different $LaB_6$ coverages and after annealing at 850°C for 30 min. $1M.L.=5.81 \times 10^{14}$ La atoms $/cm^2$.

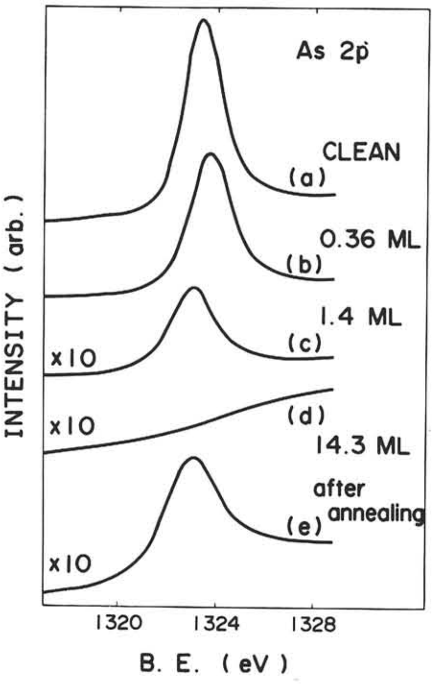


FIG. 2 As2p core level spectra at different $LaB_6$ coverages and after annealing at 850°C for 30 min.

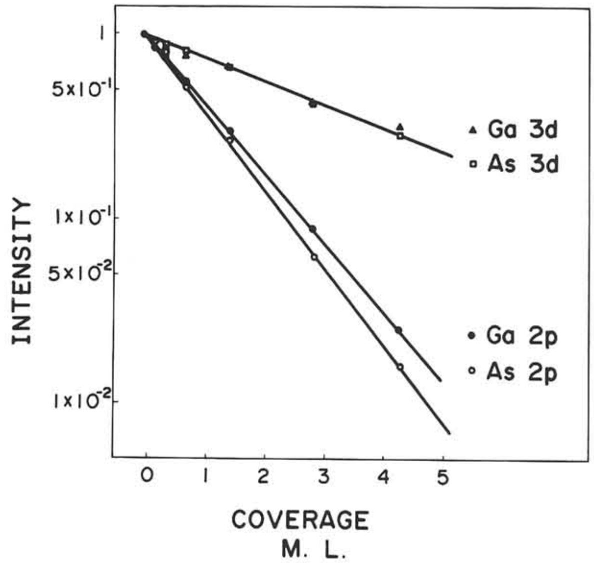


FIG. 3 Ga2p, As2p, Ga3d, and As3d XPS intensities as a function of $LaB_6$ coverage.

GaAs substrate at room temperature. Both intensities of Ga2p and As2p core levels at $E_B$ =1117.8 eV and $E_B$=1323.0 eV, respectively, decrease monotonously with increasing coverage of the $LaB_6$ films, where $E_B$ is the binding energy from the Fermi level. In Fig. 3, peak heights of Ga2p and As2p core levels normalized to those of clean surface are plotted as a function of the $LaB_6$ coverage. The plots show that both core level intensities attenuate exponentially. This is explained by assuming that the $LaB_6$ film forms continuously and uniformly without nuclear formation on the GaAs(001) surface. These results are contrasted to the case of Al and Au[7]. The behavior of Ga3d ( $E_B$=19 eV ) and As3d ( $E_B$=41 eV ) core level intensities versus $LaB_6$ coverage is consistent with that of Ga2p and As2p, if we take into account the escape depth for each photoelectron kinetic energy.

Furthermore, XPS measurements were carried out for samples annealed at 850°C for 30 min. in the MBE chamber after $LaB_6$ was deposited to about 100°A in thickness. This heat treatment does not affect essentially the Ga2p and Ga3d core level spectra as shown in Figs. 1 and 2. The As2p peak after annealing in Fig. 2 is probably due to $As_4$ adsorption on the surface of $LaB_6$ film. The $As_4$ adsorption must have occurred when annealing was made in the MBE chamber, where residual $As_4$ vapour exists to some extent even after the molecular source were turned off. These results indicate that the interface between $LaB_6$ and GaAs dose not react even at high temperatures. The Bls core level energy was observed to shift due to crystallization of the $LaB_6$ film in agreement with the change in RHEED pattern.

b) RBS

Fig.4 shows the RBS channeling spectrum of the same annealed sample as used in XPS measurements. Also shown is the spectrum for the specimen prepared at the same procedure but without annealing. Close resemblance between the two is consistent with the XPS results and again supports that intermixing of La, Ga, and As atoms do not occur exceeding the depth resolution of less than 100 Å in the present RBS measurements.

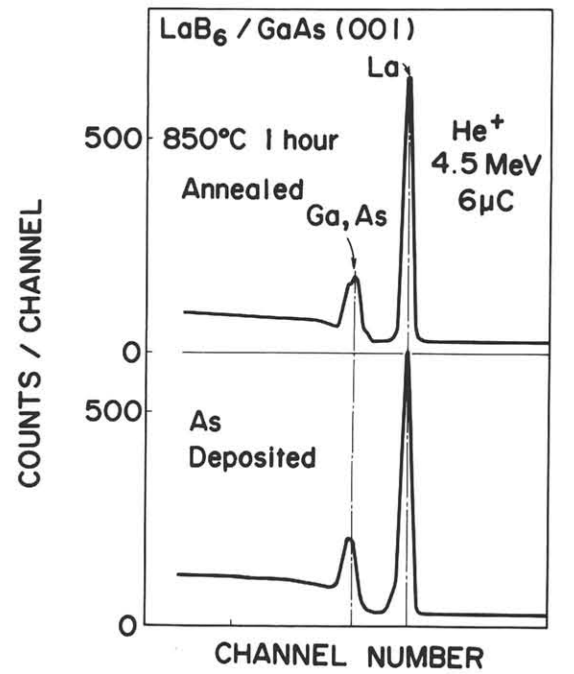


FIG. 4 Comparison of <001> RBS channeling spectra for as-deposited and after 850°C annealing for 30 min. Thickness of $LaB_6$ film is about 25 M.L. ( 100 Å ).

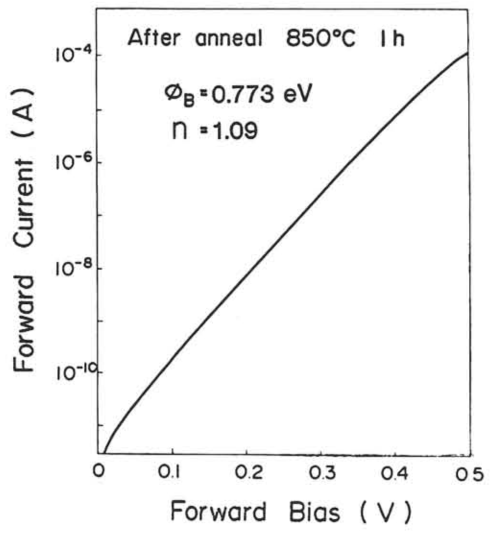


FIG. 5 Forward I-V characteristics of the $LaB_6$/GaAs(001) Schottky diode after annealing at 850°C for 1 hour.

c) Electrical measurements.

The ideality factor n and the barrier height $\phi_B$ of the $LaB_6$/GaAs(001) Schottky diode were obtained from the forward biased I-V data. Fig.5 shows semilog plots of forward biased curve after annealing. Table 2 shows values of n and $\phi_B$ for samples of as-deposited and after anneling at 850°C for 1 hour in the $H_2$ atmosphere. These values do not change much, however , both n and $\phi_B$ show a tendency of slight decreasing due to annealing. Some fluctuations were observed in n and $\phi_B$ measurements. This should be attributed to the oxidation of $LaB_6$ and GaAs and/or the desorption of As atoms during annealing. In any case, the values in Table 2 represent typical ones and show fairly low n and $\phi_B$ which is much higher than expected from the work function of $LaB_6$[6).

## §4 Summary

We have proposed $LaB_6$ as the new self aligned gate material for GaAs IC, and examined the thermal stability of the $LaB_6$/GaAs(001) interface and the I-V characteristics of the $LaB_6$/GaAs(001) Schottky diode. The interface is very stable against the high temperature annealing, and the ideality factor and barrier height are satisfactory for application to GaAs MESFET's.

| | As-deposited | 850°C 1hour annealed |
|---|---|---|
| n ideality factor | 1.15 | 1.09 |
| $\phi_B$ (eV) barrier height | 0.814 | 0.773 |

TABLE 2 Comparision of the ideality factor and barrier height between as-deposited and after annealed samples.

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