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W/Cr/Au/SiO_2 Composite Alignment Mark for Fabrication of Interference/Diffraction Hot Electron Devices

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1.Introduction

Interference/diffraction of hot electron in semiconductors is attractive scheme as a new principle of electron wave devices[1]. To confirm the interference phenomena, we proposed the device with double slit and multi-fine electrodes[2]. The period of the interference pattern by the double slit is expressed by $L\lambda/d$ where L is distance from the slit to multi-fine electrodes, λ is the wavelength of hot electron and d is pitch of the slit. When we assumed 0.2 ps as phase breaking time for electron with the energy of 0.1eV, L must be less than 200nm in GaInAs. As the wavelength is 20nm for the electron energy of 0.1eV, the product of the slit pitch and the electrode pitch must be smaller than 2000nm^2.

Most powerful tool to fabricate ultrafine arbitrary pattern is electron beam lithography(EBL). Double-slit consists of buried fine heterostructure in our scheme. So, multilevel EBL process with regrowth is required and stable alignment mark in regrowth must be established. In previous reports[2,3], we used tungsten and platinum as mark material. However, the mark detection in these reports had problems in reproducibility, so the establishment of the reliable alignment process is necessary to fabricate reproductive nano-devices.

In this report, we proposed a new alignment mark by W/Cr/Au/SiO_2 composite structure. Deformation after regrowth became very small in this structure so it provides stable alignment even regrowth was performed before overlay of EBL. By using this technique, we fabricated the structure with buried 40nm-pitch GaInAs/InP grating aligned 50nm-pitch fine multi-electrodes.

2.Requirement as mark and former problems

In order to align EBL before and after regrowth, marks that can be used after regrowth are needed. For this purpose, marks are required to two points: first, the marks have high detection gain and the second is no deformation during OMVPE regrowth.

Detection gain of mark position is strongly dependent on backscattering coefficient of the mark material and the edge profile[4]. The backscattering coefficient is proportional to the thickness and square of atomic number(Z). This means that mark material should have larger backscattering coefficient than that of substrate and have steep edge profile.

Gold(Z=*79*) is the most conventional material as mark material. However, severe deformation was observed after GaInAs/InP OMVPE regrowth because of the reaction with grown materials or substrate due to low melting point of Ga-In-Au alloy.

Although tungsten(Z=*74*) is stable during regrowth and no deposition was observed on mark, it was difficult to form sharp mark edge. Conventional evaporation with liftoff was difficult due to high melting point and deposition of sputtering had a problem of uniformity and broader edge.

In case of platinum(Z=*78*), we could deposit by evaporation and got a sharp edge profile, although lately we found this material was not so stable in OMVPE as tungsten. The regrowth had no selectivity and a GaInAs layer was grown on the marks, resulting noise in detection signal. In order to achieve a reliable detection, the grown layer on the marks was removed before fabricating electrodes. As shown in Fig.1 Pt mark surface became rough after the regrowth. So noise was introduced in

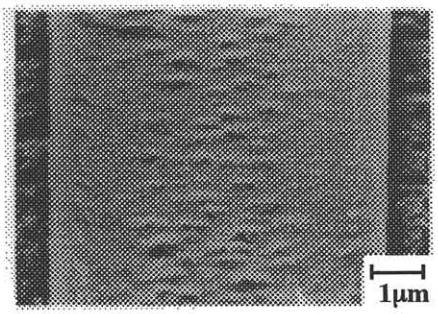

Fig.1 Surface of Pt mark after regrowth by OMVPE.The regrown layer was removed.

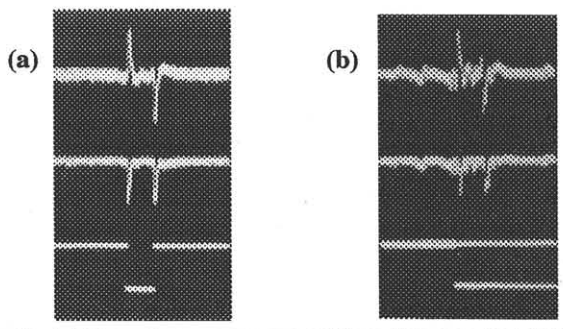

Fig.2 (a) Detection wave form of Pt mark before regrowth. (b) Detection wave form of Pt mark after regrowth.

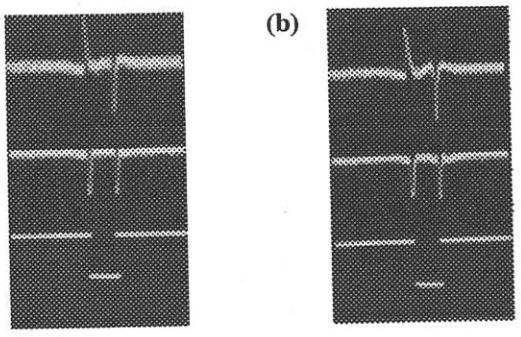

Fig.3(a) Detection wave form of composite mark before regrowth. (b) Detection wave form of composite mark after regrowth.

detection signal due to this rough surface and affected an error in detection of positions as shown in Fig.2(b). Although position recognition of marks was still possible and next EBL was performed, poor reproductivity was observed.

3.W/Cr/Au/SiO_2 composite alignment mark

To improve alignment mark, we proposed a composite structure with W layer and SiO_2 layer for mark protection. In this structure, main material is 100 nm-thick Cr/Au, which is the most common for mark because of its high detection gain and easy handling. To prevent deformation by reaction with grown material or surface of sample, a thin (30nm) tungsten layer was inserted between Cr/Au and surface of the sample and SiO_2 layer covers the Au surface. Although the tungsten layer was deposited by sputtering, small thickness caused little problem in the thickness nonuniformity. Cr and Au were formed by evaporation and liftoff, followed by deposition of a 100-nm-thick SiO_2 layer by CVD. To expose GaInAs/InP surface, SiO_2 was removed except for the mark region. After the regrowth, some GaInAs grains were deposited on SiO_2 layer covering the mark. These induced noise in detection signal, so removed by swabs with water. Growth on SiO_2 depends on area size of the SiO_2 and a small area results a small deposition of grain. Detection signal before and after the regrowth are shown in Fig.3. These show almost no change between before and after regrowth.

4.Fine structure by using composite mark

A structure with buried grating and stripe electrodes was fabricated. Fabrication procedure is almost same as former reports[2,3], except we used precise O_2 ashing to improve the resist pattern and citric acid solution for GaInAs etchant. Due to the reliable alignment by composite mark, we can make the sample with reproductivity in multi-level EBL process. Figure 4 shows cross-sectional SEM view of fabricated structure. A 40-nm-pitch buried double slit and 50-nm-pitch Cr/Au electrodes are aligned with overlay accuracy of 20 nm. The product of the slit pitch and the electrode pitch is reached 2000nm^2, that is threshold to observe interference pattern above mentioned.

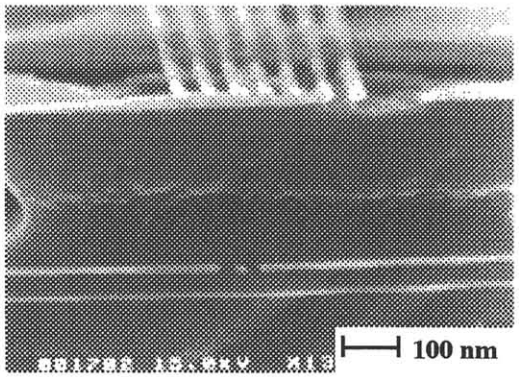

Fig.4 SEM view of aligned structure by composite mark. Pitch of double slit is 40nm while pitch of electrode is 50nm.

We have applied this composite mark system in fabrication of the double-slit device under a magnetic field (which has a 40nm-pitch double-slit and two 350nm-width segmented collectors)[5], and also confirmed its feasibility.

5.Conclusions

W/Cr/Au/SiO_2 composite structure was proposed for alignment mark of nano-fabrication process with regrowth. To prevent deformation of gold in regrowth, gold mark was sandwiched by thin tungsten layer and SiO_2 layer. Deformation of mark after regrowth became very little. Even though the mark formation is slightly complicated, W/Cr/Au/SiO_2 composite mark provides good reproducibility of process and we fabricated the structure with buried 40nm-pitch GaInAs/InP grating aligned 50nm-pitch fine multi-electrodes in multi-level EBL process. So the composite alignment mark is promising for multilevel EBL process involving crystal regrowth.

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