Nuclear Inst. and Methods in Physics Research B 414 (2018) 74–78

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research B

journal homepage: www.elsevier.com/locate/nimb

Ambient-temperature diffusion and gettering of Pt atoms in GaN with surface defect region under ^{60}Co gamma or MeV electron irradiation

Ruixiang Hou[a], Lei Li[a], Xin Fang[a], Ziang Xie[a], Shuti Li[b], Weidong Song[b], Rong Huang[c], Jicai Zhang[c], Zengli Huang[c], Qiangjie Li[d], Wanjing Xu[a], Engang Fu[a], G.G. Qin[a,*]

[a] State Key Lab for Mesoscopic Physics, School of Physics, Peking University, Beijing 100871, People's Republic of China
[b] Guangdong Engineering Research Center of Optoelectronic Functional Materials and Devices, Institute of Opto-electronic Materials and Technology, Guangzhou 510631, People's Republic of China
[c] Suzhou Institute of Nano-Tech and Nano-Bionics, Chinese Academy of Sciences, Suzhou 215123, People's Republic of China
[d] Wuxi ELPONT Radiation Technology co., LTD, Wuxi 214151, People's Republic of China

ARTICLE INFO

Keywords:
Ambient-temperature diffusion and gettering of Pt atoms in GaN
Surface defect region
^{60}Co gamma irradiation
MeV electron irradiation

ABSTRACT

Generally, the diffusion and gettering of impurities in GaN needs high temperature. Calculated with the ambient-temperature extrapolation value of the high temperature diffusivity of Pt atoms in GaN reported in literature, the time required for Pt atoms diffusing 1 nm in GaN at ambient temperature is about 19 years. Therefore, the ambient-temperature diffusion and gettering of Pt atoms in GaN can hardly be observed. In this work, the ambient-temperature diffusion and gettering of Pt atoms in GaN is reported for the first time. It is demonstrated by use of secondary ion mass spectroscopy that in the condition of introducing a defect region on the GaN film surface by plasma, and subsequently, irradiated by ^{60}Co gamma-ray or 3 MeV electrons, the ambient-temperature diffusion and gettering of Pt atoms in GaN can be detected. It is more obvious with larger irradiation dose and higher plasma power. With a similar surface defect region, the ambient-temperature diffusion and gettering of Pt atoms in GaN stimulated by 3 MeV electron irradiation is more marked than that stimulated by gamma irradiation. The physical mechanism of ambient-temperature diffusion and gettering of Pt atoms in a GaN film with a surface defect region stimulated by gamma or MeV electron irradiation is discussed.

1. Introduction

As an important semiconductor operating in the ultraviolet-red spectral region, GaN has received intensive and extensive studies over the past three decades [1–4]. Pt is a kind of important element for GaN and it has been extensively investigated as metal contacts, such as Ohmic- and Schottky-contacts, on GaN-based semiconductor devices [5–8]. Most of those studies primarily focus on the contact morphology and interface interactions. The diffusion of Pt atoms in GaN is a basic issue and its diffusion data are needed for design, reliability and performance improvement of III-nitride semiconductor devices [9], however, little study on diffusion of Pt atoms in GaN has been reported in literature. Pt atoms diffusion in GaN under the temperature range of 500–900 °C has been studied and the diffusivity of Pt at the temperatures indicated has been obtained [10,11]. Calculated with the ambient-temperature extrapolation value of the diffusivity of Pt atoms in GaN reported in literature [10], the time required for Pt atoms diffusing 1 nm in GaN at ambient temperature is about 19 years. Therefore, the ambient-temperature diffusion of Pt atoms in GaN can hardly be observed. To our best knowledge, none of study on ambient-temperature diffusion or gettering of Pt atoms in GaN has been reported.

In our previous study, it was demonstrated that ^{60}Co gamma-ray or 5 MeV electron irradiation could stimulate the ambient-temperature diffusion and gettering of the implanted Au atoms from the bulk to the surface defect region of a Si wafer [12–13]. In this work, the phenomenon of ambient-temperature diffusion and gettering of impurities in GaN is studied for the first time. Here, Pt atoms are implanted into a GaN film and a surface defect region is introduced by plasma. Secondary ion mass spectroscopy (SIMS) is well known as the most useful analysis method for impurity depth profiles in surface or near-surface regions of solid samples because of the parts-per-million to parts-per-billion sensitivity [14]. By means of SIMS measurement, it has been found that under ^{60}Co gamma-ray or 3 MeV electron irradiation, Pt atoms can diffuse at ambient temperature from the bulk to the surface defect regions of the GaN films. The physical mechanism of this phenomenon is discussed.

* Corresponding author.
E-mail address: qingg@pku.edu.cn (G.G. Qin).

http://dx.doi.org/10.1016/j.nimb.2017.10.028
Received 26 July 2017; Received in revised form 24 October 2017; Accepted 25 October 2017

2. Experiment details

The 3.5-μm-thick GaN films used in this work were grown by metal-organic chemical-vapor deposition (MOCVD) on sapphire substrates. Pt ions with energy of 350 keV were implanted into GaN film samples, named GaN:Pt. The implantation dose of Pt ions was 1E14/cm^2. Rapid thermal annealing (RTA) was carried out on the GaN:Pt samples at 800 °C for 120 s in nitrogen ambient. During RTA, the GaN:Pt samples were faced down on another GaN film to minimize the possible decomposition. This technique has been used by some authors in literature [11,15]. To introduce surface defect regions on GaN:Pt samples, some of the GaN:Pt samples were treated by helium plasma in an inductively coupled plasma (ICP) system with power of 50 and 750 W in 2 min. During ICP process, no bias power was used and therefore the etching effect could be negligible. Circulating water was used to cool the samples and the temperature rise during plasma treatment was less than 35 °C, measured by thermocouple. After introducing surface defect regions, ^{60}Co gamma irradiation with doses of 1000 and 5000 Gy or 3 MeV electron irradiation with dose of 5000 Gy, which is nearly the minimum controllable dose of the electron accelerator, were done. The temperature rise of the irradiated GaN:Pt samples during gamma or electron irradiation was less than 1 or 10 °C, respectively, measured by thermistor thermometer. The concentration distributions of Pt atoms in GaN:Pt samples were measured by use of SIMS.

3. Results

It can be seen in Fig. 1a, the concentration distribution of Pt atoms in an as-implanted GaN:Pt sample (green line) and that in an annealed GaN:Pt sample (black line), both of which were neither introduced surface defect regions nor irradiated by ^{60}Co gamma-ray or 3 MeV electrons, are approximate Gaussian shaped profiles. Hereinafter, the annealed GaN:Pt sample is referred to as control sample. Fig. 1b shows the dependence of Pt concentration distributions in a GaN:Pt sample with a surface defect region produced by plasma with power of 750W on gamma irradiation doses. Here, it should be noted that, in Fig. 1a and b, the black lines correspond to the same sample. It can be clearly seen that after irradiated by ^{60}Co gamma-ray with dose of 1000 Gy, the Pt concentration in the surface region of the sample increases and that in the Pt implanted region decreases, meaning some of Pt atoms diffuse and are gettered from the Pt implanted region to the surface defect region of the GaN:Pt sample. After the GaN:Pt sample was irradiated again by ^{60}Co gamma-ray with a dose of 4000 Gy, i.e. the gamma irradiation dose was added to 5000 Gy, the concentration of Pt atoms in the surface defect region becomes higher and that in the Pt implanted region becomes lower, which indicates that, with increasing the dose of gamma irradiation, more Pt atoms diffuse and are gettered from the Pt implanted region to the surface defect region of the GaN:Pt sample.

Fig. 2a or b shows the Pt concentration distributions in GaN:Pt samples which were introduced surface defect regions produced by plasma with different powers and subsequently irradiated by ^{60}Co gamma-ray or 3 MeV electrons, respectively. As shown in Fig. 2 a, after introducing a surface defect region produced by plasma with power of 50 W and subsequently gamma irradiation with dose of 1000 Gy, the Pt concentration in the region within about 20 nm from the top surface of the GaN:Pt sample increases a little. Fig. 2 b shows that the Pt concentration distribution in an another GaN:Pt sample, which were introduced a surface defect region produced by plasma with power of 50W and subsequently irradiated by 3 MeV electrons with dose of 5000 Gy, shifts toward the surface defect region compared with that in the control sample without a surface defect region and electron irradiation, and the displacement distance of the peak position is about 12 nm. When the plasma power alone is up to 750 W and the dose of gamma or electron irradiation remains unchanged, the surface concentration of Pt atoms in ^{60}Co gamma-ray or 3 MeV electrons irradiated GaN:Pt samples increases markedly with a top surface concentration of 5.4E18 or 2.1E19/cm^3, which is about 18 or 90 times, respectively, as high as the top surface concentration of Pt atoms in control sample. The great increase in the surface defect region produced by plasma with a higher power and the decrease in the Pt implanted region of Pt atoms indicate that a large amount of Pt atoms in the Pt implanted region diffuse and are gettered to the surface defect regions of the GaN:Pt samples at ambient temperature. The ambient-temperature diffusion and gettering of Pt atoms in GaN:Pt is more obvious with increasing the plasma power.

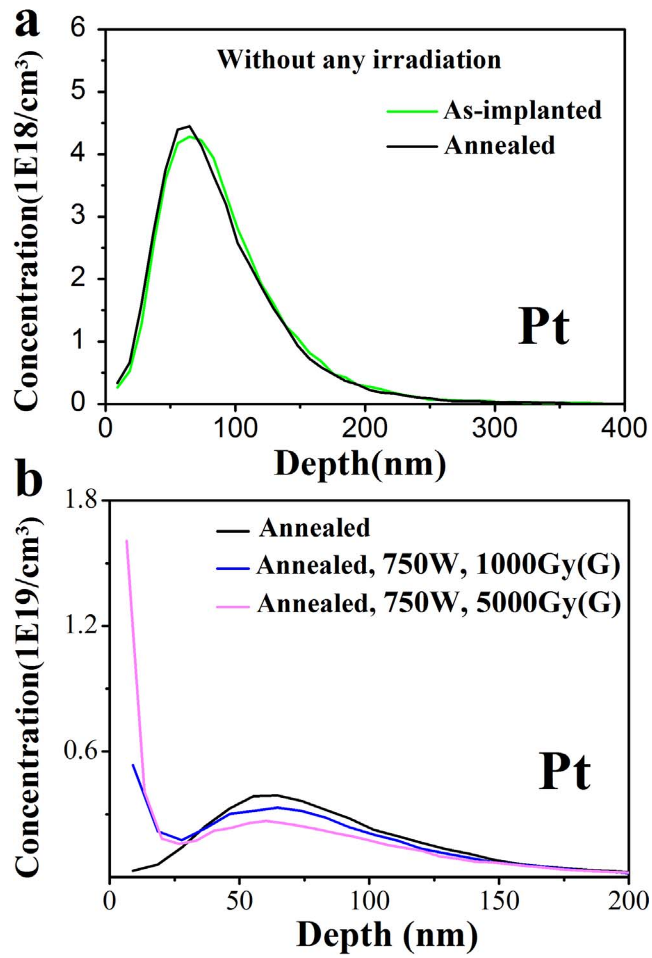

Fig. 1. a) The concentration distributions of Pt atoms in the as-implanted and annealed GaN:Pt samples. b) The concentration distributions of Pt atoms in the annealed GaN:Pt samples which were introduced a surface defect region by plasma with power of 750 W and subsequently irradiated by ^{60}Co gamma-ray (G) with doses of 1000 and 5000 Gy and the concentration distribution of Pt atoms in an annealed GaN:Pt sample which were neither introduced a surface defect region nor irradiated by ^{60}Co gamma-ray (G).

As shown in Fig. 3, the surface topography and roughness of the GaN:Pt samples were examined by using AFM. It is supposed that the surface damages of the GaN:Pt samples induced by plasma and gamma or electron irradiation can be reflected by the surface roughness value Rq. The Rq value of the annealed GaN:Pt sample was 0.14 nm. After treated by plasma with power of 50 W in 2 min, the Rq value of the annealed GaN:Pt sample was 0.18 nm, and subsequently after gamma irradiation with a dose of 1000 Gy and electron irradiation with a dose of 5000 Gy, the Rq values of the samples increased slightly to 0.20 and 0.26 nm, respectively. For another annealed GaN:Pt sample, after treated by plasma with power of 750 W in 2 min, the Rq value of the sample was 0.41 nm, and subsequently after gamma and electron irradiation with a same dose of 5000 Gy, the Rq values of the samples increased to 0.54 and 0.56 nm, respectively. It can be seen that the Rq value of a plasma treated GaN:Pt sample increases with increasing