ANALYSIS OF SCRATCHES GENERATED ON GAN SUBSTRATES DURING POLISHING

TRACK OR CATEGORY
Wear

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INTRODUCTION
Gallium nitride (GaN) is of particular interest due to its direct wide band gap energy (3.4 eV), high breakdown field, high electron saturation velocity and outstanding physicochemical properties [1-2]. For device applications, a GaN film is generally prepared by metal organic chemical vapor deposition (MOCVD) on sapphire substrates. However, in these heteroepitaxial GaN layers, the lattice and thermal mismatch between GaN and sapphire leads to a large number of dislocations [3]. As a result, flat, clean and undamaged surface is essential to form homo-epitaxial GaN layers with a low dislocation density [4]. However, GaN is very difficult to achieve an ideal polishing efficiency because of its high hardness and stable chemical properties [5]. Mechanical polishing with hard abrasives such as diamond and alumina particles can achieve flatness rapidly, but it can introduce scratch damages [6]. Wet etching can planarize GaN surface without damage by using photo electrochemical treatment, hot phosphoric acid, and molten KOH [7], but it produces rough surface. An etching method, which termed catalyst-referred etching (CARE) has been reported to produce an atomically flat damage-free surface of GaN [8], but the removal rate was just 3.4-3.8 nm/h [5]. Chemical-mechanical polishing (CMP) is considered to be an effective method to realize atomic-level smooth and damages free surface of materials. The studies of Hayashi et al. [9] suggested the importance of the selection of abrasive particles and led to the conclusion that abrasive should be softer than GaN to suppress the introduction of sub-surface damage layers.

Colloidal silica based slurry is one of the possible candidates to achieve a damage free surface with a true CMP process as colloidal silica is much softer than GaN [10]. Hideo Aida et al. [11] reported the CMP process of gallium face of GaN with colloidal silica based slurry. In their studies, there were a lot of scratches generated during polishing process, which under the condition of abrasive particle size and concentration of 40nm and 40% respectively. It took him about 150 h to obtain damage-free surface. In our previous published work, we got damage-free surface within 9 h by using Al\(_2\)O\(_3\) and colloidal silica slurry respectively [12].

The purpose of this work is to make clear of the principal influence factors in scratches on the surface of GaN during CMP process, to fulfill controllable and optimization CMP process, and provide a reference basis for the material removal mechanism of GaN.

MAIN BODY
2.1. The influence of polishing pressure to scratch
Oxidant H\(_2\)O\(_2\), pH regulator H\(_3\)PO\(_4\) and abrasive particles colloidal silica with the average sizes of 100 nm were contained in the slurry under different kinds of pressures (2.1 Psi, 5.6 Psi and 8.4 Psi). to planarization GaN. The surface
topography and roughness were evaluated by AFM (Bruker Dimension Icon), the results were shown in Fig.1 and Fig.2. As we see, the roughness of the surface of GaN and the removal rate increased as the increase of pressure, indicating that pressure plays a crucial important role on both scratch and the removal rate of GaN.

Fig.1 AFM images (a), (c), (d) (30×30 μm²) of GaN substrate surface after polished under different kinds of pressure. Images (b) (d) (f) correspond to scratch depth of (a) (c) (d)

2.2. The influence of oxidant to scratch

CMP is a complicated process, incorporated both the chemical and mechanical effects, and the removal is controlled by the slower one [11]. GaN, categorized as hard-to-process materials due to their strong stability against chemicals, thus, oxidation process is the rate limiting step in the CMP processing of GaN [13]. Here, we used an oxidant A with stronger oxidation ability than H₂O₂, H₃PO₄ as pH regulator and colloidal silica whose average size is about 110 nm as abrasive particles to polishing GaN under different kinds of pressure (2.1 Psi, 5.6 Psi and 8.4 Psi). To elucidate the effect of oxidant alone, a baseline sample of slurry containing H₂O₂ was also prepared under the same conditions described above. The results show that the slurry with oxidant A shows higher material removal rate (MRR) than that slurry with H₂O₂, as shown in Fig.2. Besides, the MRR presents larger magnitudes along with the increased of pressure. All those facts explained that oxidant A plays much better oxidation ability to facilitate the MRR of GaN. In order to observe the surface morphology clearly, AFM images were measured, as shown in Fig. 3. There is no scratch on the GaN polished under 2.1 Psi and 5.6 Psi, indicating that increasing of the thickness of oxidative products on GaN surface benefits to removing scratches. While there are a few scratch on the surface of GaN after being polished under the down pressure of 8.4 Psi. Based on this, we speculated that too much pressure applied in GaN CMP could increase the etching depth of abrasive particles, which is higher than both the oxidation rate and the MRR in unite time, resulted in scratches on GaN surface.

Fig.2. MRR of GaN polished by slurries with two kinds of oxidizer under different down pressure.
Fig. 3 AFM images (a), (b), (c) (30×30 μm²) of GaN substrate surface after polished under different kinds of pressure by slurry with oxidant A. Images (d) correspond to scratch depth of (c).

2.3. The influence of the size of abrasive particles to scratch

In order to evaluate the size of abrasive particles’ effect on GaN, a slurry contained three kinds of diameter of SiO₂ abrasive particles, oxidant A, pH regulator H₃PO₄ under 5.6 Psi pressure are used. And the results are shown in Fig.4 and Fig.5. As it indicated, we can easily see that the MRR, as well as the roughness, decreased as the decrease of the size of abrasive particles. This result was also confirmed by our previous work, for the fact that the decrease of colloidal silica size resulted in lowering mechanical function, and reducing the removal rate of GaN as well. But laws for the quality of polished GaN surface development are different from former work. The roughness increased with the decrease of abrasive particle size here, as shown in Fig. 5, there are a few of scratches on polished GaN surface, indicated that lower mechanical function will minish oxidation under oxidant A somehow.

Fig. 4 Dependence of the GaN remove rate on the size of abrasive particles.

Fig. 5 AFM images (30×30 μm²) of GaN substrate surface after polished by slurry with (a) 40nm, (b) 26nm SiO₂ abrasives and oxidant A. Images (c), (d) correspond to scratch depth of (a) (b).

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KEYWORDS
GaN, CMP, Scratch, AFMMM, colloidal silica