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Study on fundamental polishing characteristics in chemical mechanical polishing of gallium arsenide (GaAs) wafer

D. Yi [1], J. Li [1,2], J. Cao [1,2]*

[1]. *School of Mechanical, Electronic and Control Engineering, Beijing Jiaotong University, Beijing 100044, China;*
[2]. *Key Laboratory of Vehicle Advanced Manufacturing, Measuring and Control Technology, Ministry of Education, Beijing 100044, China.*

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Chemical mechanical polishing (CMP) experiments were carried out to evaluate the effect of the process parameters on the polishing characteristics of GaAs wafers. CMP of the GaAs wafers was conducted on a commercial polisher; the polishing slurry was freshly prepared from analytical grade materials prior to each experiment. The experimental results indicated that (1) the surface roughness Ra decreases on increasing the rotational speed of the polishing pad and polisher head, and polishing load; (2) the polishing load is one of the main factors that affect the total thickness variation (TTV). With the increase in the polishing load, the TTV of the wafer was reduced accordingly; (3) the material removal rate (MRR) increases on increasing of the rotational speed of the polishing pad, the rotational speed of polisher head, and the polishing load; the change of polishing load has the most obvious effect on the MRR.

Key words: GaAs, Chemical mechanical polishing, Polishing characteristics, Surface roughness.

INTRODUCTION

Gallium arsenide (GaAs) wafer has been widely utilized from macroscale to nanoscale devices for illumination, photoelectric detection, conversion of solar energy. etc., due to its high direct bandgap, saturated electron velocity and electron mobility. For example, GaAs wafer, with its nano-level, smooth, super-flat and damage-free surface, is suitable for metal-organic chemical vapor deposition to produce high- performance flexible solar cells and light emitting diodes (LED) [1, 2]. In machining process, GaAs wafer first encounters a sawing process that introduces defects and/or fracture damage deep into the wafer subsurface, because of its high hardness and brittle nature. Subsequently, lapping and polishing processes are adopted to remove this saw-induced damage and produce a nominally damage-free surface.

At present, chemical mechanical polishing (CMP) is applied as one of the most efficient treatments to produce nano-level smooth surface [3, 4]. In the literature, it is found that various chemical slurries have been used in CMP of GaAs wafers. Matovu *et al*. investigated GaAs removal rates in the presence of H_2O_2 and silica particles and compared them with those obtained in the presence of other oxidizers such as sodium iodate and sodium periodate. Their findings showed that the formation of the oxides of Ga and As is thermodynamically feasible in the aqueous slurries used for polishing of GaAs surfaces; in the absence of mechanical polishing, chemical disslurry of GaAs in aqueous slurries of oxidizers such as $NaIO_3$, $NaIO_4$, and H_2O_2 of 3mM concentration is negligible except in slurries of H_2O_2 at pH 10 and pH 12, attributed to the formation of a passivating layer of relatively stable Ga_2O_3 [4]. McGhee *et al*. proposed a three-step mechanism for GaAs removal in aqueous slurry containing H_2O_2 and ammonia [5].

Moreover, some studies also focused on the CMP characteristics of GaAs wafers. Yu *et al*. found that if SiO_2 particles are used in the polishing of the GaAs surface, high polishing speed can bring high rate of tribochemical removal without damage to the surface matrix of GaAs [6]. Wu *et al*. investigated the CMP of GaAs for transmission electron microscope observation and their findings showed that two-step polishing with NH_4OH and H_2SO_4 after conventional ion milling is an effective method to obtain improved surface quality [7]. Ookawa *et al*. found that the material removal rate (MRR) decreases and the surface roughness increases with increase in polishing time if the polishing pad is used for a long time [8].

However, in terms of the CMP of GaAs wafer, there are still many theoretical and technical problems unresolved. In this work, the fundamental polishing characteristics, i.e., the influence of the polishing parameters on the surface roughness, flatness, and MRR, are experimentally studied. Meanwhile, the topographic features of work-surfaces, and the XRD spectrum of the work-surfaces were observed to clarify the material removal mechanism.

MATERIALS AND METHODS

CMP operations of the GaAs wafers were conducted on the commercial polisher (ES36B-4P-4M by Zhejiang Morinaga Co., Ltd., shown in Figure 1) under the processing parameters shown in Table 1 to elucidate the CMP characteristics. The

*To whom all correspondence should be sent:
E-mail: jgcao@bjtu.edu.cn

polishing slurry was composed of oxidizer, dispersant, complexant, pH regulator, and abrasives. In detail, sodium chloride, sodium benzenesulfonate, sodium pyrophosphate, sodium carbonate, and colloidal silica dispersion were used as oxidizer, dispersant, complexant, pH regulator, and abrasives, respectively.

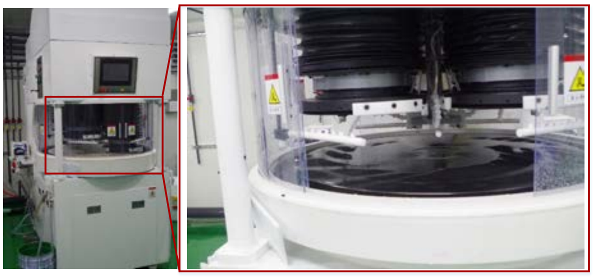


Fig. 1. Experimental setup for CMP of the GaAs wafer

Table 1 Experimental conditions

Polishing head	Rotating speed (r/min)	20, 30, 40, 50
	Load (N)	50, 70, 90, 110
Polishing pad	Rotating speed (r/min)	20, 30, 40, 50
Slurry	Slurry supplying rate (mL/min)	500
	Slurry temperature (℃)	16
Polishing time	10 min	

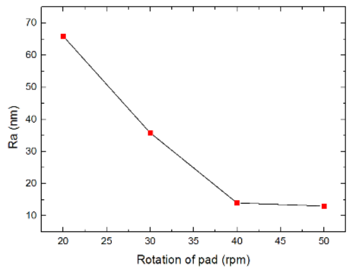
The GaAs wafers used in this work were provided by Jiangxi Deyi Semiconductor Technology Inc. The wafer has a diameter of 4 inch. One of its sides had been lapped and its surface roughness Ra was 110 nm while the other side was not polished. The slurry supplying rate was 500 mL/min, the polishing slurry temperature was 16℃, the rotational speed of the polishing head and polishing pad was changed from 20 r/min to 50 r/min. Load during polishing applied to the wafer varied from 50 to 110N. After CMP, the specimens were ultrasonic rinsed in DI water for 5 min, and then dried off by air spray gun for measurements. The surface roughness and the topography of the polished wafers were evaluated with a surface profiler (Nanovea, MG210). The material removal rate (MRR) was calculated by weighing the wafers before and after CMP. In this study, the total thickness variation (TTV) was used to evaluate the flatness of the GaAs wafers. The thickness at five different points was measured by a micrometer, the difference between maximum thickness and minimum thickness was defined as the TTV.

RESULTS AND DISCUSSION

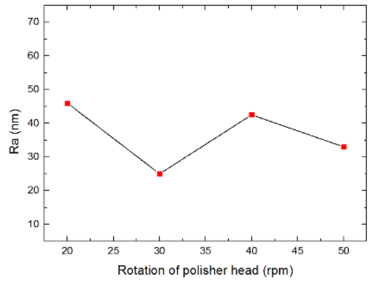
Surface roughness

The effect of CMP process parameters on the roughness is shown in Figure 2. It can be figured out that the surface roughness Ra decreases with the increasing of the rotational speed of polishing pad and polisher head, and polishing load.

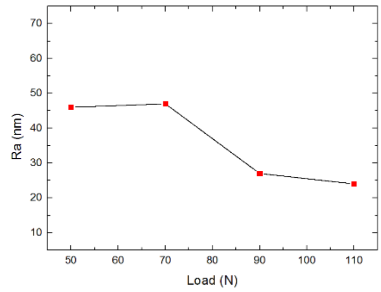
It is particularly interesting to note that the rotational speed of the polishing pad and the polishing load have a great influence on the roughness. Concretely, when the rotational speed of the polishing pad was in the range of 20-40 rpm, the surface roughness was significantly reduced with the increase in rotational speed; when the polishing load was bigger than 70N, the load increase caused an obvious reduction in the surface roughness. However, the rotation of the polisher head had a little influence on the variation of the surface roughness.



(a) Influence of rotation of polishing pad



(b) Influence of rotation of polisher head



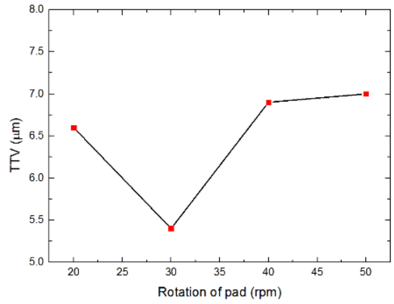
(c) Influence of polishing load

Fig. 2. Relations between roughness and process parameters

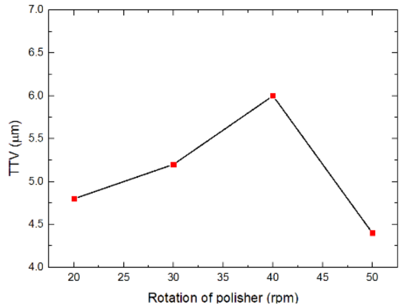
TTV

Figure 3 shows the effect of CMP process parameters on the TTV. It can be seen that the change in the rotational speed of the polishing pad and polisher head has little influence on the TTV. Meanwhile, the increase in the rotational speed of the polishing pad and polisher head leads to an increase in TTV, i.e., the TTV becomes worse. The reason why the TTV is getting worse can be ascribed to the severe vibration induced by the rotation of the polishing pad and polisher head at a high speed.

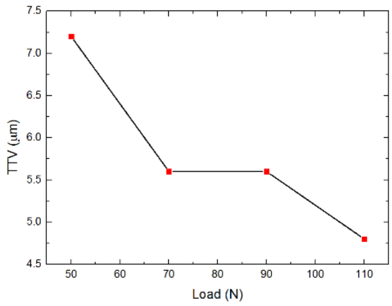
The polishing load is one of the main factors that affect the TTV. With the increase in the polishing load, the TTV of the wafer will be accordingly reduced. This is because at a small polishing load, the GaAs wafer suspends on the polishing pad (Figure 4(a)), resulting in an ineffective contact between the polishing pad and the GaAs wafer. The material removal volumes at different positions of the wafer surface are not equal, therefore, the TTV of the polished wafer is relatively high at low polishing load; as the polishing load rises, the GaAs wafer contacts fully with the polishing pad (Figure 4(b)), improving the TTV of the GaAs wafer.



(a) Influence of rotation of polishing pad

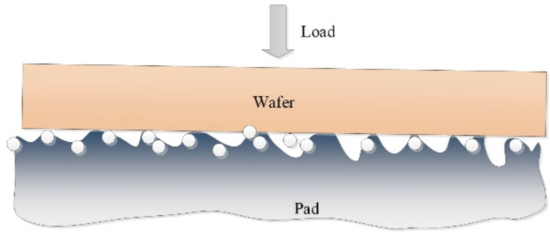


(b) Influence of rotation of polisher head

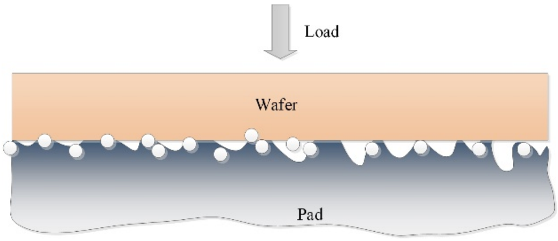


(c) Influence of polishing load

Fig. 3. Relations between TTV and process parameters



(a) At low polishing load



(b) At high polishing load

Fig. 4. Contact state between the polishing pad and the wafer

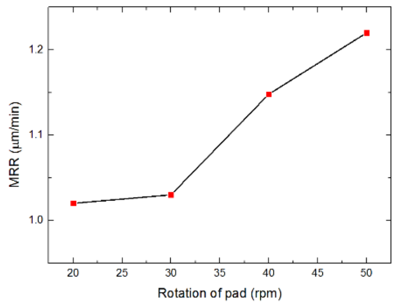
MRR

The effect of process parameters on the MRR in CMP of the GaAs wafer is plotted in Figure 5. It is seen from the graph that the values of MRR increase with the increase in the rotational speed of the polishing pad, the rotational speed of polisher head, and the polishing load. In the CMP process, Preston equation is widely accepted to predict the polishing material removal behavior [8]:

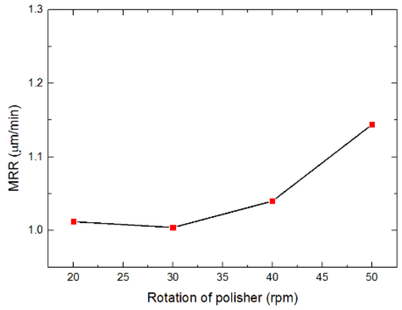
$$\mathrm{MRR}=kPv \tag{1}$$

where P is the applied load, V is the velocity at any point on the wafer relative to the pad, and k is the Preston coefficient depending on the processing conditions, such as the slurry, the pad and the process environment.

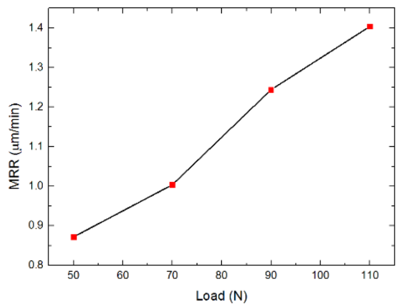
From the Preston equation it is known that MRR is proportional to the relative velocity between the pad and the wafer surface and the applied load. This agrees with the findings in this study. However, the change in the polishing load has the most obvious effect on the MRR, followed by the polishing pad rotational speed, while the influence of the polishing head rotational speed on the MRR is relatively weak. This is possibly so because the increase in the polishing load can increase the friction force between the surface of the substrate and the pad, thus, the MRR increases with the increase in the polishing load. The polishing pad rotational speed has an obvious, while the polishing head rotational speed has a weak influence on the relative velocity of the wafer to the pad. Therefore, the influence of the polishing head rotational speed on the MRR is relatively weak.



(a) Influence of rotation of polishing pad



(b) Influence of rotation of polisher head

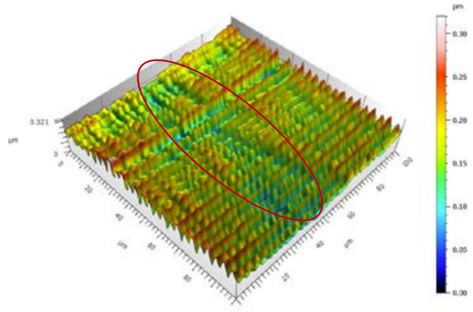


(c) Influence of polishing load

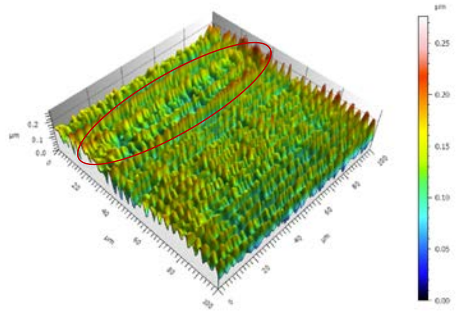
Fig. 5. Relations between MRR and process parameters

Surface topography and material removal mechanism

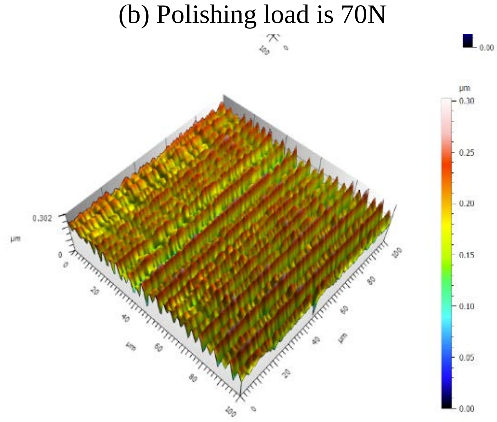
Figure 6 shows the surface topography images of the polished GaAs wafers observed by a surface profiler, when the polishing load is 50N, 70N, 90N, and 110N, and the rotational speeds of the polishing pad and polishing head are 40 r/min and 40 r/min, respectively. From Figure 6(a) it can be seen that there is a local dent on the surface of the workpiece when the polishing load is 50 N, meaning that the MRR is different at the different locations. As shown in Figure 6(b), this phenomenon can be also observed when the polishing load is 70 N. However, the local dents suddenly disappear when the polishing load gets a rise up to 90 N (Figure 6(c)) and 110N (Figure 6(d)), indicating that the MRR is almost the same at different locations. This agrees with the discussed findings



(a) Polishing load is 50N

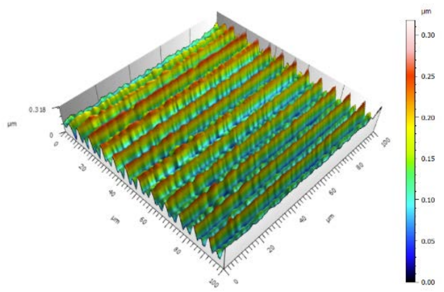


(b) Polishing load is 70N



(c)

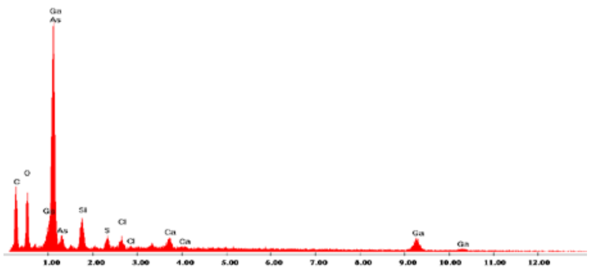
Polishing load is 90N



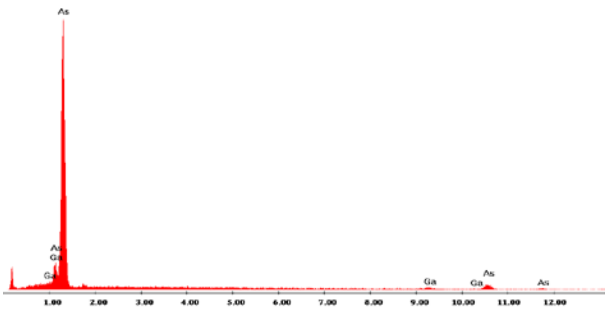
(d) Polishing load is 110N

Fig. 6. Surface topography images of the polished GaAs wafers

In order to elucidate the material removal mechanism in the CMP process, chemical analysis of the GaAs wafer surface before cleaning and after cleaning was performed by XRD, when the polishing load was 50N, and the rotational speeds of the polishing pad and polishing head were 40 r/min and 40 r/min, respectively. Comparing XRD chemical analysis results of the GaAs wafer surface before cleaning and after cleaning, it is recognized that there are O, Si, Cl, S, Ga, and As elements on the surface before cleaning (Figure 7(a)), while there are only Ga and As elements on the surface after cleaning (Figure 7(b)). Therefore, the material removal process is reckoned as follows: firstly, sodium chloride reacts with GaAs under the circumstances of exceedingly high pressure to form new substances with lower hardness than GaAs and then the resultant softer substances are removed by fused silica abrasive mechanically and plastically.



(a) Before cleaning



(b) After cleaning

Fig. 7. XRD spectrum of the polished GaAs wafer

CONCLUSIONS

In the present work, the fundamental polishing characteristics, i.e., the influence of the process parameters on the surface roughness, flatness, and MRR, in CMP of a GaAs wafer, were experimentally determined. The material removal mechanism in the CMP process of the GaAs wafer was discussed. The following conclusions can be drawn:

(1) The surface roughness Ra decreases on increasing the rotational speed of the polishing pad and polisher head, and the polishing load; when the rotational speed of the polishing pad is in the range of 20-40rpm, the surface roughness is significantly reduced with the increase in rotational speed; however, at a polishing load bigger than 70N, the increase in the load causes an obvious reduction in the surface roughness.

(2) The polishing load is one of the main factors that affect the TTV. With the increase in the polishing load, the TTV of the wafer is accordingly reduced.

(3) MRR increases on increasing the rotational speed of the polishing pad, the rotational speed of the polisher head, and the polishing load; the change in polishing load has the most obvious effect on the MRR, followed by the polishing pad rotational speed, while the influence of the polishing head rotational speed on the MRR is relatively weak.

(4) The material removal process in CMP of GaAs wafers is reckoned as follows: firstly, sodium chloride reacts with GaAs under the circumstances of exceedingly high pressure to form new substances with lower hardness than GaAs, and then the resultant softer substances are removed by fused silica abrasive mechanically and plastically.

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