TaC Coated Wafer Carrier for GaN MOCVD for Blue Light-Emitting Diodes

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Abstract

TaC coated graphite wafer carrier was evaluated in GaN MOCVD processes for growing blue InGaN/GaN light-emitting diodes (LEDs) on Sapphire. The properties and performance of the LEDs were compared with the ones grown on traditional SiC coated graphite wafer carriers. The results indicated that TaC coated graphite wafer carrier is compatible with the process without introducing impurity. With limited process tuning, LED grown on TaC carrier achieved the same performance and uniformity as those grown on SiC carrier. Given that TaC is more corrosion resistant than SiC in a hot ammonia and hot hydrogen environment, a TaC coated carrier could improve the tool lifetime and process stability in the GaN MOCVD production.

INTRODUCTION

The wafer carrier is one of the key components in the metal-organic chemical vapor deposition (MOCVD) tool for GaN epitaxy growth. The majority of wafer carriers were made of graphite with SiC coating to resist etching from process gases, such as hot ammonia and hydrogen. The etch resistance of the protection coating is critical to the life of wafer carriers. Traditionally, TaC coated graphite wafer carriers have been used in SiC epitaxy growth above 1600 °C and TaC coated graphite parts have also been used in SiC crystal growth above 2200°C. In previous studies[1,2], we evaluated the corrosion resistance of SiC and TaC in hot ammonia and hydrogen environments. Our study suggested that TaC showed 6 times slower etching rate than SiC in hot ammonia and more than 10 times slower etching rate than SiC in hot hydrogen. TaC is considered a promising candidate coating material for wafer carrier in GaN MOCVD process to increase the lifetime.

In this study, we explored the effects of using TaC coated graphite wafer carriers in a GaN MOCVD process to grow blue light-emitting diodes (LEDs). Properties and performance of the LEDs grown on both TaC and SiC carriers were evaluated and compared with each other.

EXPERIMENTS

The metal-organic chemical vapor deposition (MOCVD) tool used is the Veeco P75 in the Center for High Technology Materials crystal growth facility at the University of New Mexico. TaC coated graphite wafer carrier was made by Momentive Performance Materials Quartz, Inc (Strongsville, OH, USA). Commercial SiC coated graphite wafer carrier was purchased. Both carriers were made to the same dimension for the 2 inch single-wafer MOCVD tool as shown in Figure 1.

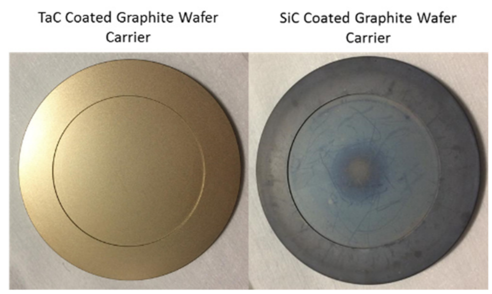


Fig. 1: Graphite wafer carriers used in Veeco P75 MOCVD tool coated with TaC (left) and SiC (right)

The n-GaN templates for all the LED samples were grown on sapphire substrates with identical growing conditions. For the growth of the top 3 layers in Figure 2, TaC and SiC coated wafer carriers were used, respectively, for performance comparison. Two sets of process conditions were designed to evaluate the effects of using TaC carrier. Table I lists the growth conditions for the 5 samples.

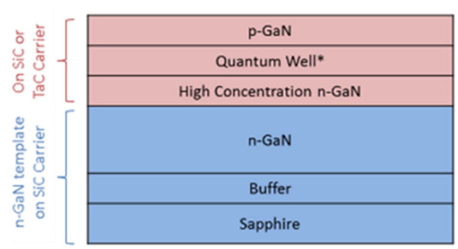


Fig. 2: Structure of LED Samples.

TABLE I
EXPERIMENT AND SAMPLE DESCRIPTION

Set	ID	Wafer Carrier	Process Control
A	A1	SiC	Thermal Couple Reading
	A2	TaC	
	A3	SiC	
B	B1	SiC	Growth Rate
	B2	TaC	

*Samples in Experiment Set B include a 60 nm InGaN underlayer before the quantum well growth

The as-grown LED wafers were characterized by time of flight secondary-ion mass spectroscopy (TOF-SIMS), atomic-force microscopy (AFM) and x-ray diffraction (XRD) to study the quality of the deposits, such as impurity, surface roughness, and quantum well thickness.

To evaluate the light-emitting performance of the LED wafers across the wafer, photoluminescence (PL) and electroluminescence (EL) tests were performed at 5 locations of each wafer along the radial direction. Metallic contact mesas of 100 um squares were fabricated on top for EL measurement.

RESULTS

Growth Rate

In Experiment Set A, a thermal couple, which was installed below the heating elements as shown in Figure 3, was used for temperature control and its target temperature was set the same for both carriers. As a result, the temperature reading from the pyrometer on the wafer is 85°C lower when TaC carrier was used than that when SiC carrier was used. The cooling water temperature on the chamber lid was also lower, indicating a lower wafer temperature. The observations were believed to be caused by the lower emissivity of TaC carrier (0.3 for TaC and 0.8 for SiC). Since the system is controlled by the feedback of the thermal couple below the heating element, TaC might reflect more heat to the thermal couple and reduce radiation heat loss from the top surface, which caused the heater power reduction. As a result of lower wafer temperature using TaC carrier, the growth rate of quantum well was about 10% higher than using SiC (1340 nm/hr with TaC vs. 1230 nm/hr with SiC).

In Experiment Set B, growth rate was used to control the wafer temperature. The film quality and light output results shown below indicate that such growth rate control was effective for achieving the same LED quality after changing from SiC to TaC wafer carrier. It was found that the same growth rate can be achieved with 7% less power consumption on TaC carrier than on SiC carrier for the growth of high concentration n-GaN layer. We suspect the low emissivity of TaC led to less heat radiation loss than SiC. The low surface roughness of TaC also contributed to a more effective heat conduction from the carrier to the wafer.

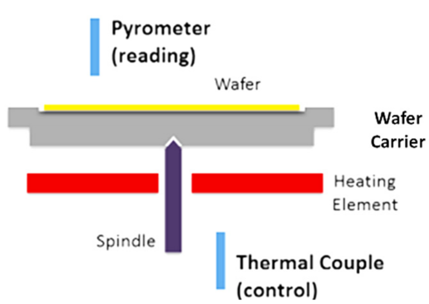


Fig. 3: Temperature control and measurement system

Film Quality

To identify if TaC would introduce impurities to the MOCVD chamber or to the LED wafers, samples were grown on SiC carrier before and after the growth using TaC carrier. TOF-SIMS results on the 3 samples in Experiment Set A indicated that no extra impurity was introduced by using TaC coated carrier (Figure 4). The higher carbon concentration in A2 was due to the lower wafer temperature discussed above. Once the same wafer temperature was maintained in Experiment Set B, there was no extra carbon detected. Given that TaC coating was generated from a process above 2000 °C, such thermal stability was within expectation.

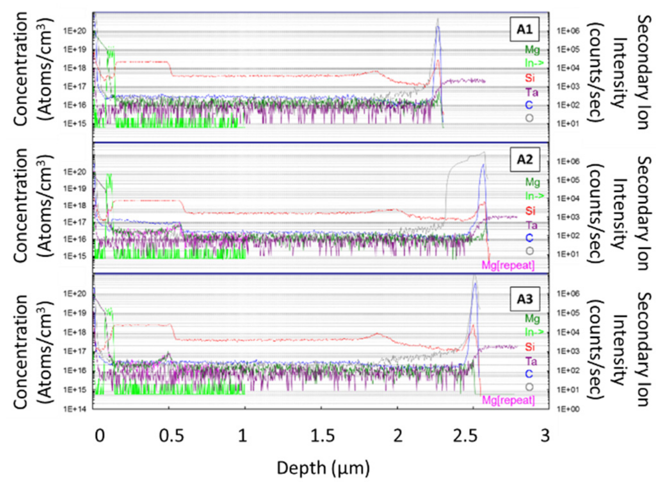


Fig. 4: TOF-SIMS Results for A1, A2, and A3
Test data. Actual results may vary.

To compare the film quality of LEDs grown on TaC and SiC carrier under the same wafer temperature, the growth rate was measured using reflectometer setup in the MOCVD reactor (a useful metric to equalize the real temperature of the GaN epi) and maintained the same for both carriers in Experiment Set B. The AFM and XRD results showed very similar epitaxial structures on both the LEDs. Table II displays the surface roughness and quantum well thickness measurement results by AFM and XRD respectively.

TABLE II
SURFACE ROUGHNESS AND LAYER THICKNESS FOR B1 AND B2

Sample	Ra (nm)	Well (nm)	Barrier (nm)
B1	0.91	2.6	11.3
B2	0.89	2.5	11.4

Light Output

As expected, in Experiment Set A, sample A2 emitted lights with a wavelength longer than sample A1 and A3 due to a higher incorporation of In in the quantum well grown at lower wafer temperature (Figure 5).

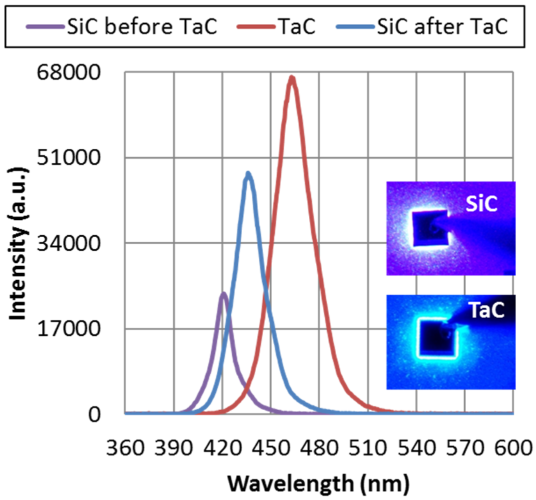


Fig. 5: EL measurement results of Experiment Set A.
Test data. Actual results may vary.

In Experiment Set B, EL tests were performed on 100 um square LED mesa at the same locations on B1 and B2 sample wafers. LED I-V response, light wavelength and output intensity were comparable for the 2 samples grown on different wafer carriers (Figure 6). The PL results on 5 spots along the radius of B1 and B2 demonstrated the uniformity of the LED performance in terms of peak wavelength and linewidth (Figure 7). It indicated that LED grown with TaC carrier can reach peak wavelength uniformity of 7 nm across a 2 inch wafer. The linewidth of 15 nm was achieved, which is comparable to LEDs grown on SiC carrier. The high wavelength and width for the central region of LED grown on SiC in Figure 7 was considered the result of a relatively thick fugitive coating at the center of the carrier.

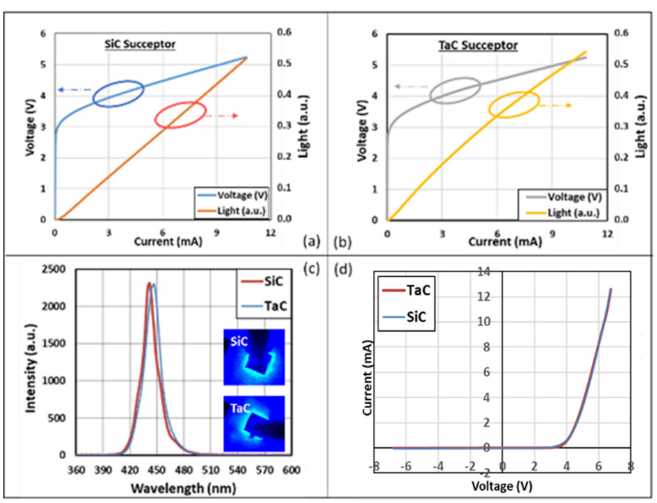
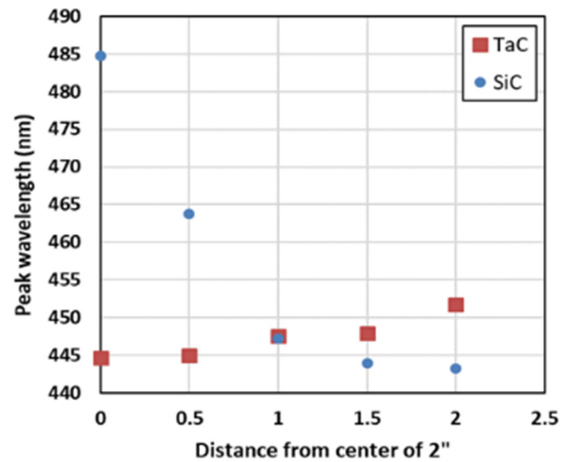
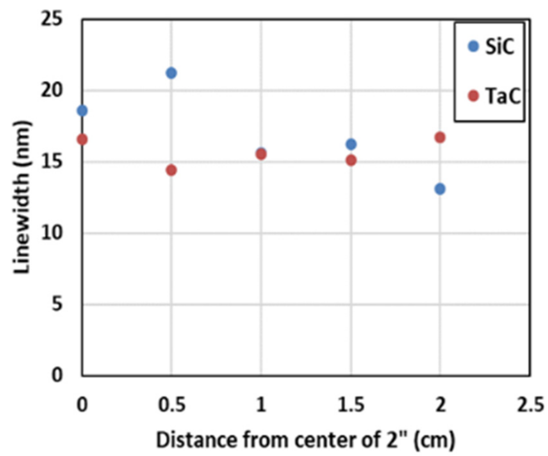


Fig. 6: LED Performance Results of (a) EL for B1 (b) EL for B2 (c) EL light output for B1 and B2 (d) V-I curve for B1 and B2
Test data. Actual results may vary.



(a)



(b)

Fig. 7: PL results for B1 and B2 indicate peak wavelength uniformity (a) and linewidth uniformity (b) across the radius of the wafer.
Test data. Actual results may vary.

Etch Resistance

In previous studies[1,2], we evaluated the corrosion resistance of SiC and TaC in hot ammonia (1400 °C, 500 torr) and hydrogen (1400 °C, 760 torr) environments. Our study suggested that TaC showed a 6 times slower etching rate than SiC in hot ammonia and a more than 10 times slower etching rate than SiC in hot hydrogen (See Figure 8). TaC is considered a promising coating material candidate for wafer carrier in GaN MOCVD process to achieve increased longevity.

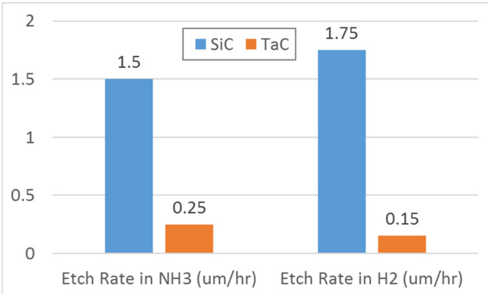


Fig. 8: Etching Rate of TaC and SiC Coating in Hot NH_3 and Hot H_2 environment
Test data. Actual results may vary

CONCLUSIONS

TaC coated graphite wafer carrier was shown to be compatible to the blue light GaN MOCVD process without introducing impurity. With limited process tuning, LED grown on TaC carrier achieved the same performance and uniformity as the ones grown on traditional SiC carrier. Given that TaC is more corrosion resistant than SiC in hot ammonia and hot hydrogen environments, it would be an excellent candidate for wafer carriers in GaN MOCVD process to help increase service life.

ACKNOWLEDGEMENTS

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ACRONYMS

MOCVD: metal-organic chemical vapor deposition
LED: Light-Emitting Diodes
TOF-SIMS: time of flight secondary-ion mass spectroscopy
AFM: atomic-force microscopy
XRD: x-ray diffraction
PL: photoluminescence
EL: electroluminescence