Heater Performance Improvement with Ceramic Coatings for GaN MOCVD Process

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Keywords: GaN, PBN, TaC, MOCVD, Heater, Coating

Abstract

Nitride and carbide coatings such as pyrolytic boron nitride (PBN) and tantalum carbide (TaC) were produced on graphite substrates via high-temperature chemical vapor deposition (CVD). Excellent thermal and chemical resistances of the PBN and TaC coatings were demonstrated in this study. Graphite cores coated with these ceramic materials provide a unique approach to achieve superb heater thermal performance and reliability in the GaN MOCVD applications.

INTRODUCTION

The compound semiconductor gallium nitride (GaN) is an enabling material for high power, high temperature and high frequency electronics. GaN devices are made using metal organic CVD (MOCVD), which typically runs with H_2 and NH_3 above 1100ºC. To heat wafers to this temperature, resistive metal heaters made of tungsten or molybdenum thin strips are common choices. However, thermal stresses caused by heating and cycling often deform the metal strips and impair the heating performance. Conversely, graphite exhibits high electrical resistance and maintains its shape and strength at high temperature, which makes it a good candidate for heating elements. The major challenge of using bare graphite heaters in MOCVD equipment is that the hydrogen species generated from H_2 and NH_3 can aggressively etch graphite. Pyrolytic boron nitride (PBN) [1] and tantalum carbide (TaC) [2], with their high-temperature stability, high purity, and high chemical resistance, are being investigated as coatings to protect the graphite heating elements in these corrosive environments. In this study, we will report the key PBN and TaC coating properties and their application to graphite heaters.

EXPERIMENT

PBN and TaC coatings were produced on graphite substrates by thermal CVD using B, Ta, N and C-containing precursors at temperatures from 1500 to 2500ºC. Both deposits were fully dense polycrystalline coatings and hermetically sealed the graphite substrates (Figure 1). High purity (99.995+%) was also achieved. The as-deposited PBN coating was typically 80 to 2,000 µm thick and exhibited a layered hexagonal crystal structure as revealed by x-ray diffraction (Figure 2). It is a similar lattice structure to that of pyrolytic graphite. TaC coating, on the other hand, had a cubic crystal structure and thickness of 20 to 50 µm. Some of the typical material properties of these two coatings can be found in Table I.

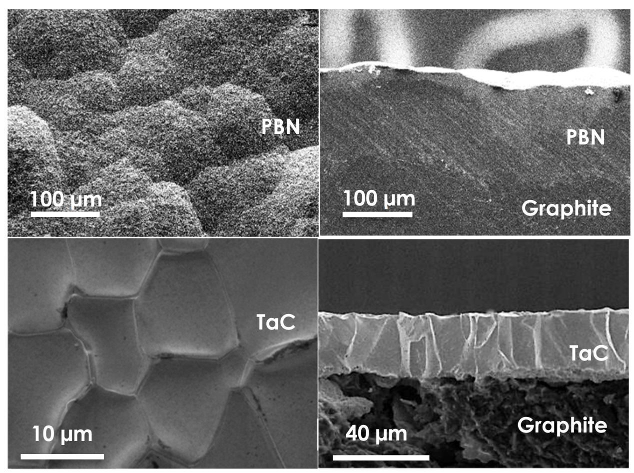

Fig. 1. SEM top view and cross-sectional view of PBN coating (top) and TaC coating (bottom) on graphite substrates

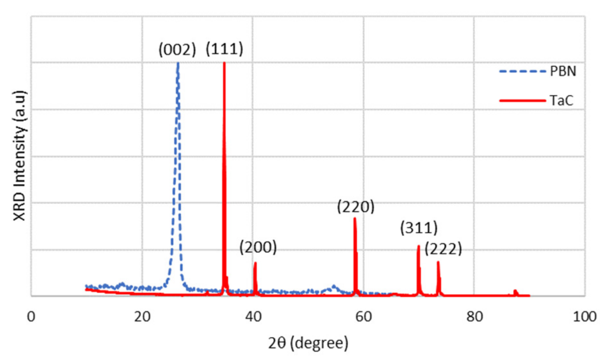

Fig. 2. X-ray diffraction (XRD) spectra of as-deposited PBN and TaC coatings

TABLE I. MATERIAL PROPERTIES OF PBN AND TAC COATINGS PREPARED BY THERMAL CVD

Coating	Density g/cm^3	CTE @ 1000ºC $10^{-6}/K$	Resistivity Ohm-cm	Max Use ºC
PBN	2.1	2.0	10^{15}	2500
TaC	14.3	6.8	10^{-5}	2600

Note: Test data. Actual results may vary. Typical data are average data and not to be used as or to develop specifications.

Our thermal stability study showed that PBN coating was stable up to 2500ºC under vacuum, while TaC coating can withstand 2600ºC. Excellent coating adhesion to the graphite substrates was also demonstrated in a thermal shock test. Both coatings exhibited superb resistance to NH_3 and H_2 in a hot chemical etching test. For example, no corrosion was observed in TaC coating or the graphite substrate coated by TaC after a 20-hour NH_3 etching test at 1400ºC and 500 Torr (Figure 3). Similar test was conducted on TaC coating under atmosphere of H_2, which is also one of the process gases in GaN MOCVD. For comparison, commercial CVD SiC coatings were put through the same test. While SiC coating decomposed under H_2, TaC coating remained intact (Figure 4).

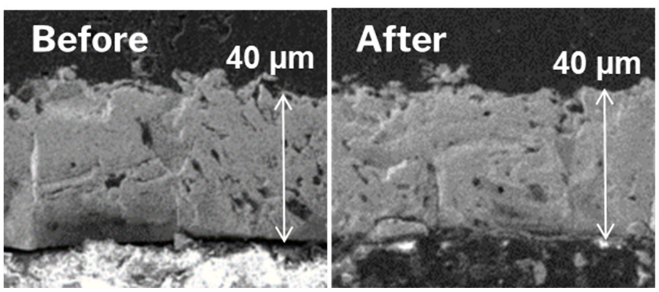

Fig. 3. SEM cross-sectional view of TaC coating on graphite substrate before and after NH_3 etching test

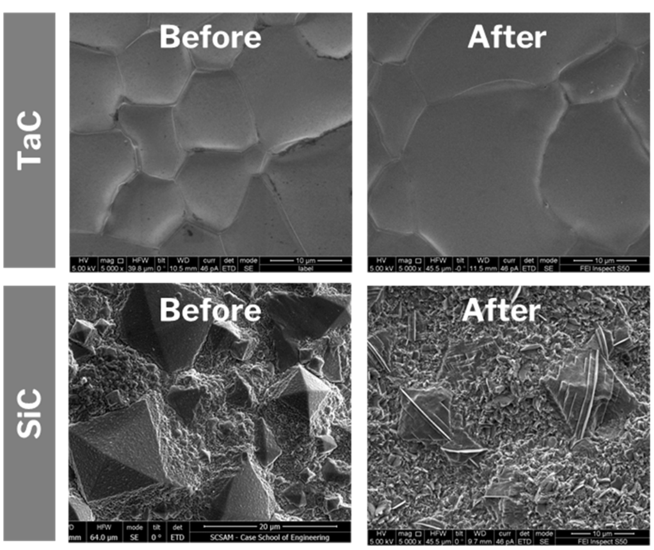

Fig. 4. SEM top view of TaC and SiC coatings on graphite substrates before and after H_2 etching test

Application

Coating graphite with PBN or TaC prevents the graphite from reacting with hydrogen species at elevated temperature (>1000ºC). This provides the opportunity to use graphite-based heating elements in MOCVD tools.

In one of the MOCVD applications, a single-zone heater with a diameter of 180 mm was manufactured by coating a spiral graphite substrate with TaC. Since TaC is electrically conductive, no graphite exposure was needed at the locations where power connections were made. This minimized the risk of substrate etching due to graphite exposure to the corrosive environment. Infrared imaging (Figure 5) revealed a uniform profile of 1100ºC across the entire surface.

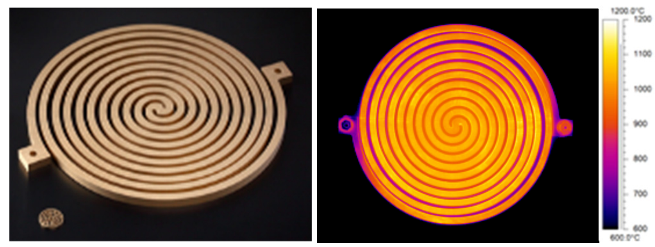

Fig. 5. TaC-coated graphite heater with a diameter of 180 mm (left) and infrared image of the heater operated at 1100ºC (right)

To achieve a desired temperature profile in large MOCVD tools, multizone heaters are often required. Figure 6 shows a large PBN-coated graphite heater (D = 800 mm) consisting of a single segment in the inner zone, two segments in the middle zone, and four segments in the outer zone. Each zone power can be independently controlled. This multizone design enables a tailored temperature profile or improved thermal uniformity during MOCVD wafer processing.

Fig. 6. Seven-segment PBN-coated graphite heater with a diameter of 800 mm

Conclusion

Thermal CVD was used to produce refractory, chemically resistant ceramic coatings of PBN and TaC on graphite substrates. High coating purity and good adhesion to the substrate were also achieved. These ceramic coatings can hermetically seal the graphite and prevent substrate corrosion in harsh environments. Graphite heaters protected by PBN and TaC coatings were developed and shown to have good thermal performance and long life in the MOCVD wafer-heating process.

REFERENCES

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ACRONYMS

CVD: Chemical Vapor Deposition
MOCVD: Metal Organic Chemical Vapor Deposition
PBN: Pyrolytic Boron Nitride
XRD: X-Ray Diffraction
SEM: Scanning Electron Microscope