

## Impact of Surface Emissivity on Crystal Growth and Epitaxial Deposition

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**Abstract.** Tantalum carbide (TaC) coating, produced in an ultrahigh temperature chemical vapor deposition (CVD) process, exhibited high thermal and chemical stabilities, low emissivity, and high purity. Low emissivity of 0.3~0.43 was measured on TaC coating at 1000°C and compared with the one of SiC coating. As revealed in both simulation and experiment, the low emissivity of TaC coatings not only improves temperature uniformity in the SiC PVT process, but also reduces power consumption in both SiC crystal growth and GaN epitaxial deposition. The results provide important guidance to process tuning when switching from a conventional graphite or SiC-coated component to its TaC-coated counterpart.

### Introduction

Tantalum carbide (TaC) with its high thermal stability, high purity, and high chemical resistance, is often used to coat graphite to suppress contamination and to protect graphite reactor components from corrosive environments [1]. TaC coating is typically applied to crucibles and guide rings in SiC physical vapor transport (PVT) process, and susceptors, carriers, and ceilings in SiC and GaN epitaxial chemical vapor deposition (CVD). Traditionally bare graphite and SiC-coated reactor components are commonly used in those processes. The metallic appearance of TaC coating is quite different from the dark surfaces of graphite and SiC coating. It suggests a different radiation behavior at high temperature. While the operating temperature of GaN and SiC epitaxial deposition ranges from 1100 to 1600°C [2, 3], SiC crystal growth can reach 2400°C [4]. Temperature uniformity and gradients are extremely important to those processes and can largely impact the process yield and product quality. Understanding the influence of TaC coating on thermal profiles is of great benefit to process control.

### Coating Preparation

TaC coating in study was generated through a proprietary ultrahigh temperature CVD process by Momentive Technologies Inc. [5]. The coating has an average thickness of 35 µm, grain size of 20 µm and roughness (Ra) of 1.5 µm. A variety of graphite grades and shapes was used as substrates to receive the coating and good coating adhesion was regularly achieved. Cross section SEM revealed a dense and conformal coating on substrate surfaces, including sharp inner corners. Impurities of B, N, Si, and Al measured on the coating by GDMS were 1 to 2 orders of magnitude lower than the ones in purified graphite. XRD and XPS analyses indicated TaC coating is highly crystalline and has a Ta

to C ratio of 1:1. SiC coating used in this study for comparison was purchased commercial product and also made by CVD process.

### Emissivity

Emissivity is a material property that gages the energy radiated from a surface. Its value is a function of temperature as well as radiation wavelength. We conducted multi-wavelength pyrometry measurement on a group of SiC and TaC coating samples at 1000°C. The emissivity spectra (Fig. 1) clearly show that TaC coating presents a much lower emissivity, ranging from 0.30 ( $\lambda = 950$  nm) to 0.43 ( $\lambda = 600$  nm), compared to SiC coating. Typical high temperature graphite emissivity is similar to or higher than that of SiC [6]. A temperature profile change is, therefore, expected in a system that employs TaC coating vs. the traditional SiC coating or bare graphite.

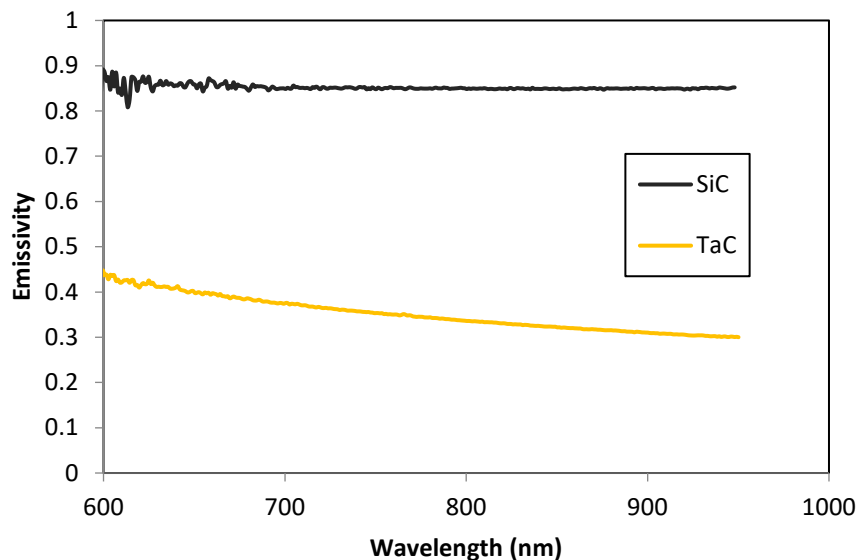


Fig. 1. Emissivity spectra of TaC and SiC coatings measured at 1000°C

### Crystal Growth

A SiC PVT process using both conventional graphite and TaC-coated graphite crucible sets was modeled to understand the impact of emissivity on temperature profile, which can lead to changes in growth rate and ingot shape. Virtual Reactor, the modeling software for crystal growth that employs global heat transfer, heterogeneous chemistry, gas flow, and mass transport, was used in this study. A TaC emissivity of 0.4 was assumed, as was zero reactivity to SiC vapor. The simulation (Fig. 2) revealed that a more uniform temperature would be achieved with the TaC-coated crucible compared to the graphite incumbent. In addition, the superb thermal and chemical stability of TaC coating prevented the carbon reaction with Si vapor. As the result, the C/Si distribution along the radial direction was more uniform with TaC coating. A 4% power reduction due to the decreased radiative heat loss was also predicted and later confirmed by experimental work at DongEui University [5].

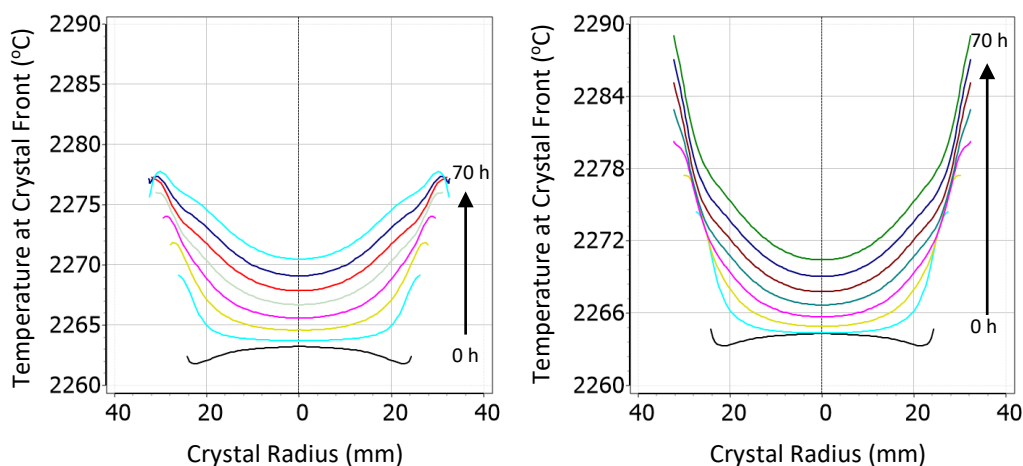


Fig. 2. Simulated SiC crystal front temperature distribution in the radial direction using TaC-coated crucible (left) and conventional graphite crucible (right) through 70 hours of crystal growth

### Epitaxial Deposition

Another study at the University of New Mexico evaluated TaC and SiC coated wafer carriers with identical dimensions in a commercial metal-organic chemical vapor deposition (MOCVD) tool (Veeco P75). GaN p-n junctions with 7-layer InGaN/GaN quantum well were deposited on sapphire substrates at 800~1100°C. Target light emitting wavelength was ~440 nm. It was found that, in order to achieve the same GaN growth rate (~1.2  $\mu\text{m/hr}$ ), 7% more power was required when using the SiC-coated carrier. The same growth rate indicated that the same wafer temperature was reached in both cases. It was further confirmed by the electrical and optical measurements on the produced GaN LEDs (Fig. 3) showing nearly identical characteristics. The low emissivity of the TaC coating on the wafer carrier resulted in less radiative heat loss and, thus, consumed less power.

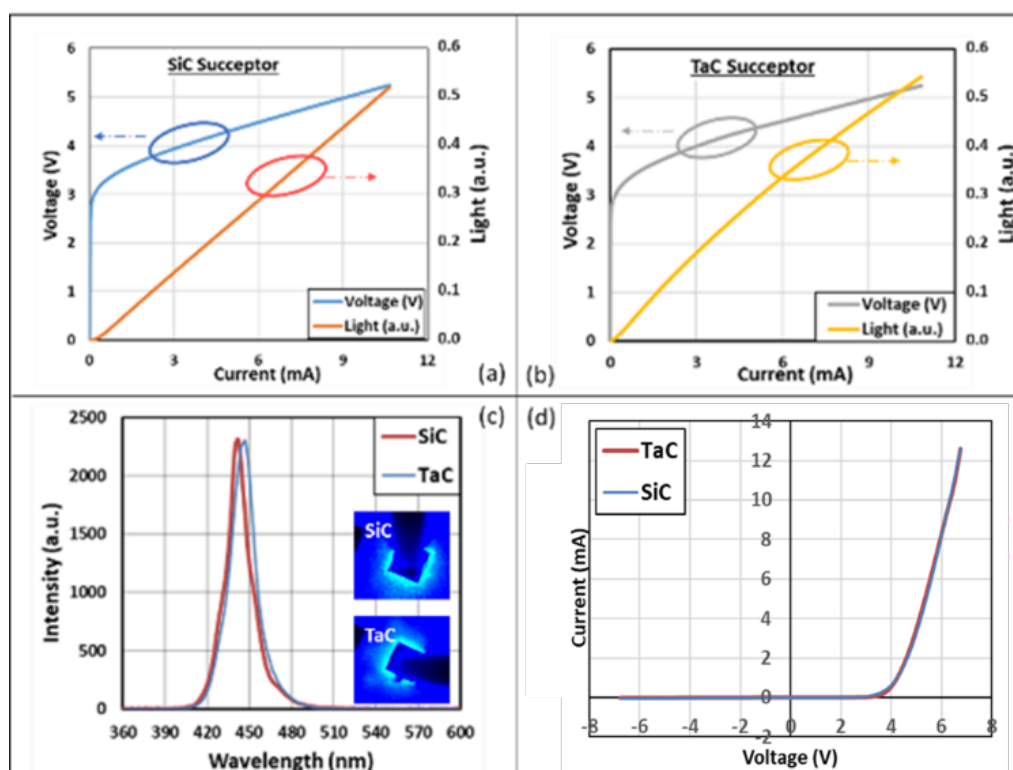


Fig. 3. Electrical and optical characteristics of LEDs produced using SiC and TaC carriers: (a) and (b) electroluminescence result, (c) electroluminescence light output and (d) V-I curve

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## Summary

TaC coating presented much lower surface emissivity at high temperature compared to SiC coating and graphite. As demonstrated by simulation and experiment, the low emissivity of TaC coatings not only improves temperature uniformity in the PVT process, but also reduces power consumption in both crystal growth and epitaxial deposition. The results provide important guidance to process tuning when switching from a conventional graphite or SiC-coated component to its TaC-coated counterpart.

## References

- [1] D. H. Lee, etc., Materials Science Forum 778-780, 26 (2014)
- [2] E. Arslan, etc., J. Phys. D: Appl. Phys. 155317, 41 (2008)
- [3] M. Ito, etc., Appl. Phys. Express, 15001, 1(2008)
- [4] M. Nakabayashi, etc., Materials Science Forum 600-603, 3 (2009)
- [5] W. Fan, etc., Materials Science Forum 22-25, 963 (2019)
- [6] Y.S. Touloukian and D.P. DeWitt, Thermophysical Properties of Matter 7: Thermal Radiative Properties (1970)