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TaC-coated graphite prepared via a wet ceramic process: Application to CVD susceptors for epitaxial growth of wide-bandgap semiconductors

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ABSTRACT

A novel sintered tantalum carbide coating (SinTaC) prepared via a wet ceramic process is proposed as an approach to reducing the production cost and improving the crystal quality of bulk-grown crystals and epitaxially grown films of wide-bandgap semiconductors. Here, we verify the applicability of the SinTaC components as susceptors for chemical vapor deposition (CVD)-SiC and metal-organic chemical vapor deposition (MOCVD)-GaN epitaxial growth in terms of impurity incorporation from the SinTaC layers and also clarify the surface-roughness controllability of SinTaC layers and its advantage in CVD applications. The residual impurity elements in the SinTaC layers were confirmed to not severely incorporate into the CVD-SiC and MOCVD-GaN epilayers grown using the SinTaC susceptors. The quality of the epilayers was also confirmed to be equivalent to that of epilayers grown using conventional susceptors. Furthermore, the surface roughness of the SinTaC components was controllable over a wide range of average roughness ($0.4 \leq Ra \leq 5$ μm) and maximum height roughness ($3 \leq Rz \leq 36$ μm) through simple additional surface treatment procedures, and the surface-roughened SinTaC susceptor fabricated using these procedures was predicted to effectively reduce thermal stress on epi-wafers. These results confirm that SinTaC susceptors are applicable to epitaxial growth processes and are advantageous over conventional susceptor materials for reducing the epi-cost and improving the quality of epi-wafers.

1. Introduction

Wide-bandgap semiconductors (e.g., SiC and GaN) are promising materials for next-generation power devices [1–5]. Power devices based on wide-bandgap semiconductors require the deposition of thick drift layers (low-doped ($<1 \times 10^{16}$ cm^{-3}) epilayers with a thickness of ~10 μm for 1–2-kV-class blocking voltage) [6] onto high-quality, large-diameter native substrates via chemical vapor deposition (CVD) or metal-organic chemical vapor deposition (MOCVD). To make wide-bandgap power devices feasible in a wide range of applications, drastic cost reduction must be accomplished, especially in terms of the epilayer formation (epi-cost), which accounts for almost half of the production cost of an epi-wafer (a single-crystal substrate with an epilayer). The epi-cost should be approximately equal to the sum of the depreciation cost (largely determined by throughput) and the expendable component cost (e.g., susceptors and/or heaters) of CVD-SiC or MOCVD-GaN epitaxial growth reactors. Because the throughput is partly affected by the lifetime (which determines the maintenance frequency) of expendable reactor components, a substantial extension of the lifetime of susceptors and/or heaters should contribute to a reduction of the overall epi-cost of wide-bandgap epi-wafers. However, CVD-SiC or MOCVD-GaN epitaxial growth conditions are more corrosive than conventional CVD-Si process conditions. CVD-SiC epitaxial growth requires high processing temperatures of 1500–1700 °C in a H_2–SiH_4–C_3H_8 gas stream [7], which cause H_2 etching of SiC-coated carbon susceptors and lead to a shortened lifetime of the SiC-coated susceptors compared to the CVD-Si process. Although MOCVD-GaN epitaxial growth requires moderate processing temperatures of 1000–1050 °C [8], the growth is conducted in a highly corrosive NH_3 gas stream, which gradually damages SiC-coated carbon susceptors and/or pyrolytic-boron-nitride (pBN)-coated carbon heaters. Replacing the susceptor/heater materials with alternative materials, e.g., TaC-coated carbon is one approach to substantially extending the lifetime of susceptors and heaters used in CVD or MOCVD processes used to prepare wide-bandgap semiconductors. Although TaC-coated carbons prepared by CVD (CVD-TaC) [9] are

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commercially available, the high cost and limited lifetime of CVD-TaC-coated carbon components hamper their application in practical CVD or MOCVD processes.

To address the high cost and short lifetime of present TaC-coated carbon materials, we previously proposed preparing ultra-thick (~100 μm) TaC-coated carbon materials on graphite via a wet ceramic process; we refer to the obtained coatings as sintered tantalum carbide coatings (SinTaCs) [10]. SinTaCs are potentially low cost and highly reliable because of their simple production scheme and defect-free dense coating layer. Furthermore, large-sized complex-shaped SinTaC components are available through optimization of the TaC slurry compositions and selection of the optimal graphite material for the substrate [11,12]. However, the SinTaC layers contain a high concentration (~100 ppm) of residual impurities that originate from the source materials (cermet-grade TaC powder and a sintering agent) [11]. In our previous studies, we found that the bulk crystal growth process (i.e., SiC and AlN growth via sublimation) with SinTaC components was not impaired by high concentrations of impurities [11,13]. In addition, high-rate GaN growth by halogen-free vapor-phase epitaxy (HF-VPE) [14] showed suppressed impurity incorporation with SinTaC components compared to the use of conventional pBN components, which led to a substantial reduction of nanopipe defect formation in HF-VPE-grown GaN layers [15].

The requirements for a coated susceptor material to be used for wide-bandgap epitaxial processes are (1) long lifetime (long-term durability and/or reusability in multiple growth/cleaning runs) to reduce the processing costs, (2) low extrinsic impurity incorporation from the susceptor material, and also (3) temperature uniformity to ensure thickness, doping concentration, and compositional homogeneities [16]. In the present work, we demonstrate the initial verification of CVD-SiC and MOCVD-GaN epitaxial growth with SinTaC susceptors and confirm that the residual impurities in the SinTaC layers do not adversely affect either growth process. Furthermore, we attempt to control the surface roughness of the SinTaC components via simple additional surface treatments and clarify another advantage in CVD applications through a two-dimensional finite-element method (2D-FEM) simulation. Finally, we demonstrate the fabrication of practical components for CVD-SiC and MOCVD-GaN epitaxial growth systems to enable future applications of SinTaC components in these systems.

2. Experimental

SinTaC test susceptors for CVD-SiC and MOCVD-GaN epitaxial growth were prepared by spraying a TaC slurry onto graphite substrates and subsequently sintering the sprayed substrates at temperatures greater than 2000 °C in a reduced-pressure Ar atmosphere [10]. The SinTaC test susceptor for CVD-SiC was a fully coated plate with dimensions of 150 × 43 × 1.5 mm^3; the susceptor for MOCVD-GaN was a fully coated disc (with a recess for a ∅2 in. substrate) with the dimensions of ∅58 × *h*19.5 mm^2. The thickness of the SinTaC layers formed on the susceptors was controlled to be ~100 μm.

The CVD-SiC epitaxial growth was carried out in a horizontal hot-wall CVD reactor, as shown in Fig. 1(a). A 4H-SiC(0001) 4°-off wafer was placed on the SinTaC plate susceptor, and the SinTaC susceptor with the wafer was installed into the reactor, which included a molded carbon fiber thermal insulator. The sample and susceptors were heated to a process temperature (SiC-coated susceptor temperature measured by a pyrometer) of 1600 °C by radio-frequency heating at a process pressure of 30 Torr. Before the epitaxial growth, H_2 etching was carried out for 30 min in a pure H_2 gas stream; the CVD-SiC epitaxial growth was then carried

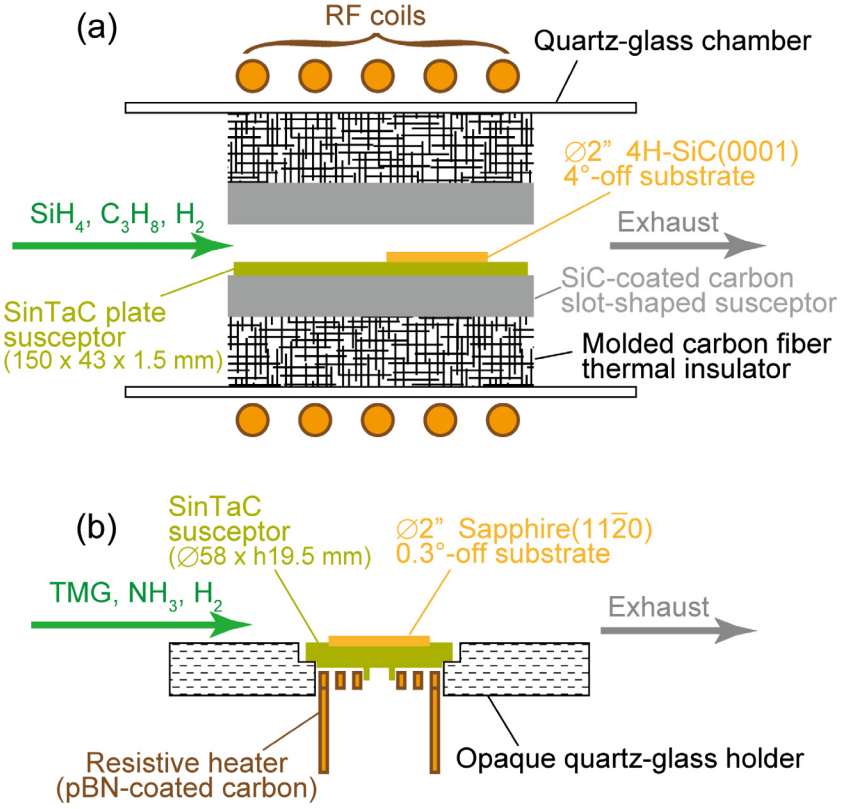

Fig. 1. Schematics of (a) a hot-wall CVD reactor for SiC epitaxial growth with a SinTaC plate and slot-shaped SiC-coated carbon susceptors and (b) a MOCVD reactor for GaN epitaxial growth with a SinTaC susceptor (TMG = trimethylgallium).