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Interfacial Structure and Reaction Mechanism of SiC/V Joints†

T. Fukai*, M. Naka** and J. C. Schuster***

Abstract

SiC was bonded to SiC using V foil at temperatures ranging from 1473K to 1673K for 1.8 to 64.8ks and 30MPa in vacuum. Interfacial reactions and microstructures were investigated using or electron probe microanalyser and X-ray diffractometer. SiC begins to join with V at temperatures above 1473K. At 1573K for 1.8 and 7.2ks, granular V₂C phase formed at the V side of the reaction zone, while the layer V₃Si phase is formed at the interface between V₂C and SiC. The same reaction structure can be observed at 1473 and 1673K for 1.8ks. Hexagonal V₅Si₃C_x phase was formed at the interface between V₃Si and SiC at 1573K for 14.4 and 21.6ks, and the interface structure of the joint became SiC /V₅Si₃C_x /V₃Si /V₂C+V /V. This complete diffusion path is correlated with the corresponding Si-V-C phase diagram. At the longer bonding time of 64.8ks, V was completely consumed, and the joint showed the layer structure of SiC/V₅Si₃C_x/V₃Si/V₂C/V₃Si/V₅Si₃C_x/SiC.

KEY WORDS: (Reaction Mechanism) (Interfacial Structure) (Ceramic) (Metal) (Diffusion) (SiC) (V) (Vanadium Carbide) (Vanadium Silicide)

1. Introduction

Silicon carbide is one of the candidates for high temperature structure components used up to 1273K with its remarkable features such as light weight, high strength and good resistance to wear. Some structural applications of ceramics require a reliable joining method with a metallic component. Compared to other joining methods such as brazing, solid state bonding provides high temperature strength in the interfacial region. However, for effective control of the interface structure, study of the phase reaction between the ceramic and the metal is necessary. While the interfacial structure, phase reaction, and the formation of titanium carbide and silicide at the SiC/Ti interface have been investigated in detail¹⁻⁵⁾, few reports exist on the SiC/V system and V is a high melting metal like titanium and also reactive with SiC. According to Schuster⁷⁾, V₅Si₃C_x, V₅Si₃, V₃Si, and V₂C are formed in the reaction zone at temperature 1573K, but this report did not characterize the

microstructures of the observed phases of the system. The aim of the present work is to examine the interfacial structure, phase reactions, and diffusion path between SiC and V.

2. Experimental Procedure

The materials used were cylindrical SiC rods of 6 mm diameter and 4 mm thickness, containing a few percent of alumina as sintering aid, and V foils of 25 μm thickness of 99.9 mass % purity. SiC /V /SiC couples were bonded under vacuum below 1.33mPa in a high frequency furnace equipped with a graphite tube. The applied bonding pressure was 30MPa. The bonding temperature ranged from 1473K to 1673K. The bonding time extended between 1.8 and 64.8ks. The phases occurring in the reaction zone were characterized by electron probe microanalysis (EPMA), and identified by x-ray diffraction with Cu · Kα diffraction.

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3. Results and Discussion

3.1 Interfacial structure

At a constant bonding temperature of 1573K, the change in microstructure and reaction phases at the interface between SiC and V were examined by changing bonding time. The microstructure and distribution of elements for a joint bonded at 1573K for 1.8ks are shown in Figs.1 and 2 respectively. V reacts with SiC, and forms two kinds of phase. The layer phase adjacent to SiC and a granular phase adjacent to V were identified as V_3Si and V_2C , respectively as shown in Fig.2. The microphotograph of SiC/ V/ SiC joint bonded at 1573K for 7.2ks is shown in Fig. 3. Vanadium still remains at the central part of the joint. The reaction phases at the interface grew with increasing bonding time from 1.8ks to 7.2ks. One is V_3Si and other is V_2C . The layer of V_3Si phase which has a thickness of $3\mu m$ is adjacent to SiC. The granular compound of V_2C which has thickness of $13\mu m$ is adjacent to V. These microstructures can be clearly seen in Fig.4, which shows the distribution of the C, Si and V elements across the interface from A to B in Fig.3. This analytical result agrees with the X-ray diffraction results shown in Fig.5. The same reaction phase can be formed in the SiC /V /SiC bonded at the conditions of 1473K for 1.8ks and 7.2ks, and 1673K for 1.8ks.

The microstructure and distribution of elements after bonding at 1573K for 14.4ks are shown in Figs.6 and 7. The reaction zone as shown in Fig.6 consists of two layers together with a granular compound. EPMA analysis in Fig.7 shows that the first layer of thickness $3\mu m$ is adjacent to SiC, containing on average 30.0at% Si and 17.5at% C, giving the composition of $V_5Si_3C_x$, and that the second layer of a thickness $2.5\mu m$ has an average composition of 63.0at% V and 21.0at% Si, giving the composition of V_3Si . Granular V_2C also appears in the V, and this V_2C must be adjacent to V_3Si . X-ray analysis of the fracture surface of the joint (Fig.8) indicates the formation of hexagonal V_2C with lattice parameters $a = 0.2904nm$ and $c = 0.4523nm$, of cubic V_3Si with $a = 0.4734nm$, and hexagonal $V_5Si_3C_x$ with $a = 0.7161nm$, $c = 0.4762nm$. Thus, at bonding conditions of 1573K and 14.4ks, the reaction phases formed established the complete diffusion path between SiC and V as SiC / $V_5Si_3C_x$ / V_3Si / V_2C / V_2C+V / V. This diffusion path is described by the tie line connecting SiC and V in the corresponding V-Si-C ternary phase diagram⁶⁾ as shown in Fig.9.

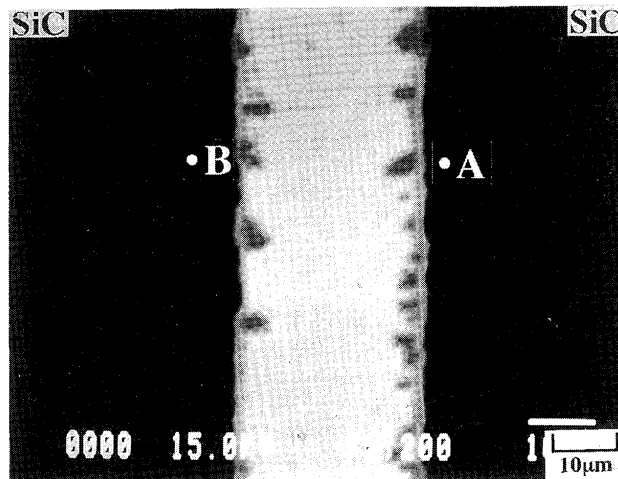


Fig.1 Microphotograph of SiC/V/SiC joint bonded at 1573 K for 1.8ks.

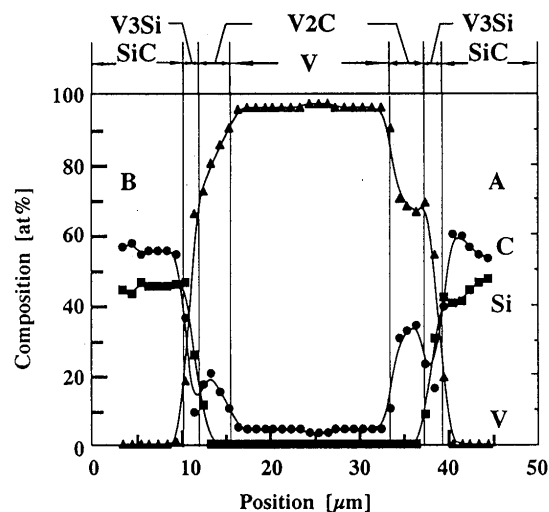


Fig.2 Elemental distribution in SiC/V/SiC joint bonded at 1573 K for 1.8 ks.

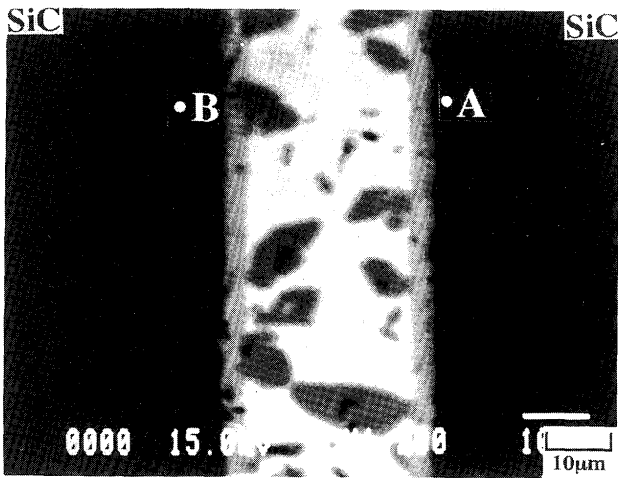


Fig.3 Microphotograph of SiC/V/SiC joint bonded at 1573 K for 7.2 ks.

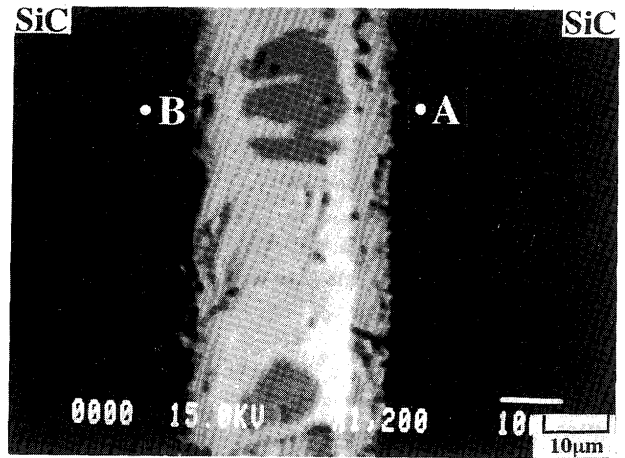


Fig.6 Microphotograph of SiC/V/SiC joint bonded at 1573 K for 14.4 ks.

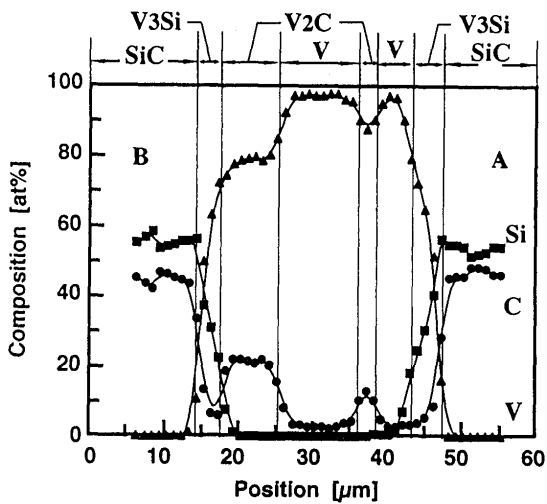


Fig.4 Elemental distribution in SiC/V/SiC joint bonded at 1573 K for 7.2 ks.

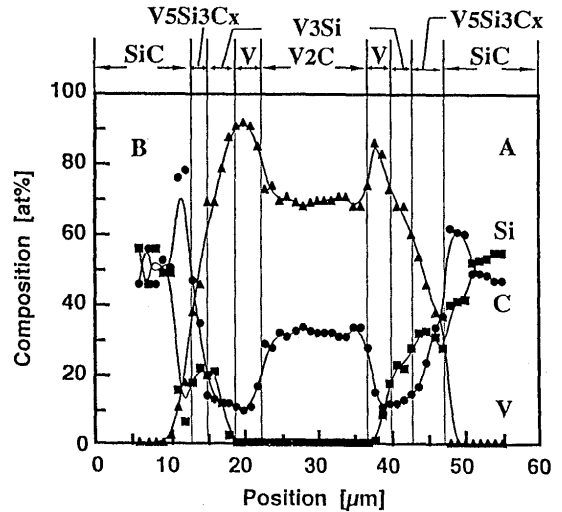


Fig.7 Elemental distribution in SiC/V/SiC joint bonded at 1573 K for 14.4 ks.

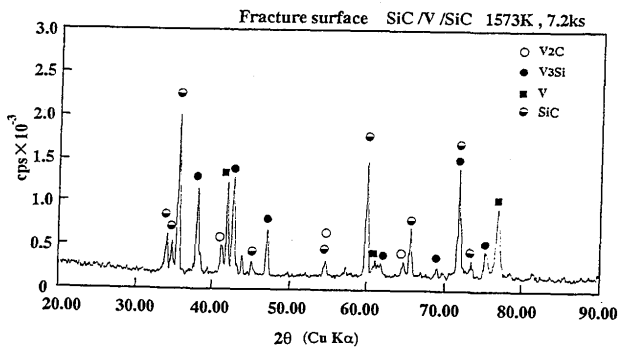


Fig. 5 X-ray diffraction pattern of the interface of SiC/V/SiC joint bonded at 1573 K for 7.2 ks.

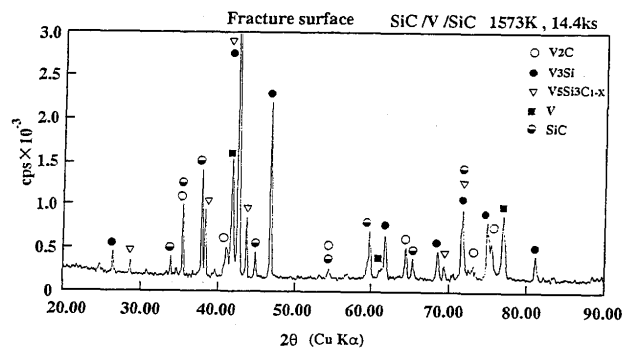


Fig.8 X-ray diffraction pattern of the interface of SiC/V/SiC joint bonded at 1573 K for 14.4 ks.

At the longer bonding time of 64.8ks at the bonding temperature of 1573K, the microstructure of SiC /V / SiC joint is shown as in Fig. 10. V at the central part of the joint was completely consumed, and changed to V₂C. The joint is composed of the layer structure as SiC /V₅Si₃C_x /V₃Si / V₂C / V₃Si / V₅Si₃C_x / SiC, as shown in the distribution of elements from A to B in the joint in Fig. 11.

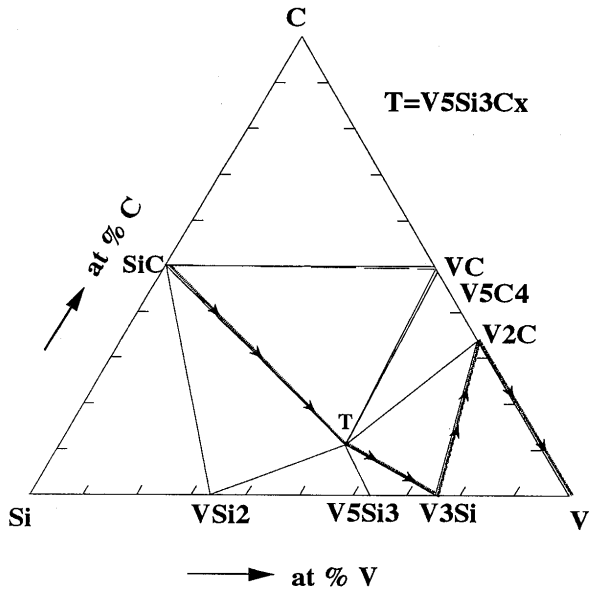


Fig.9 Diffusion path between SiC and V on the V-Si-C ternary phase diagram at 1573K.

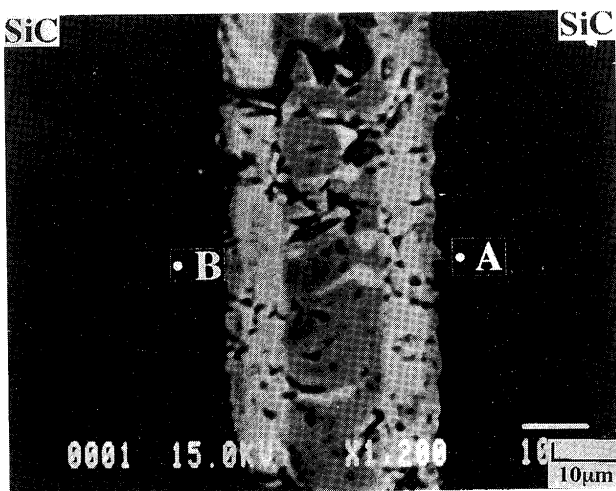


Fig.10 Microphotograph of SiC/V/SiC joint bonded at 1573 K for 64.8 ks.

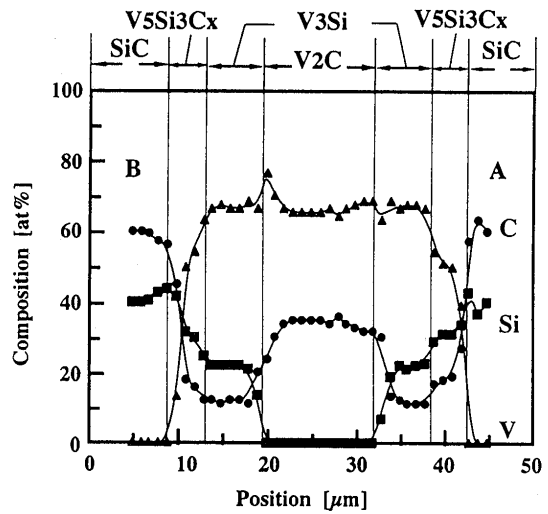
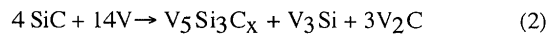
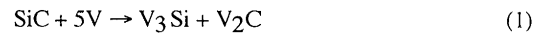


Fig. 11 Elemental distribution in SiC/V/SiC joint bonded at 1573 K for 64.8 ks.

3.2 Reaction mechanism

Fig. 12 shows the change in schematic structure of the interface between SiC and V bonded at 1573K for the bonding time from 1.8 to 64.8ks. The reaction phases are V₅Si₃C_x and V₃Si together with granular V₂C. The reaction mechanism between SiC and V is discussed using the present results. The phases of V₅Si₃C_x and V₃Si grow with increases in the bonding time. The V₂C of the central part of V grows with the bonding time. The phases at the interface between SiC and V couples are formed by the following reactions :



First, V reacts with SiC at the interface, and forms V₂C and V₃Si. Carbon diffuses faster than silicon in V, and V₂C is formed adjacent to the V, and V₃Si is formed adjacent to SiC which are represented by eq. (1) and Fig.12 a and b. The V still remains at the central part of the joint and carbon and silicon continue to diffuse from SiC to V. Then, granular V₂C is grown and V₅Si₃C_x is formed adjacent to the SiC and these are represented by eq.(2), and Fig.12 c and d.

At longer bonding times, V at the central part of joint is completely consumed, and the central part of the the V changes to V₂C or VC, which are represented by Fig.12 e and f.

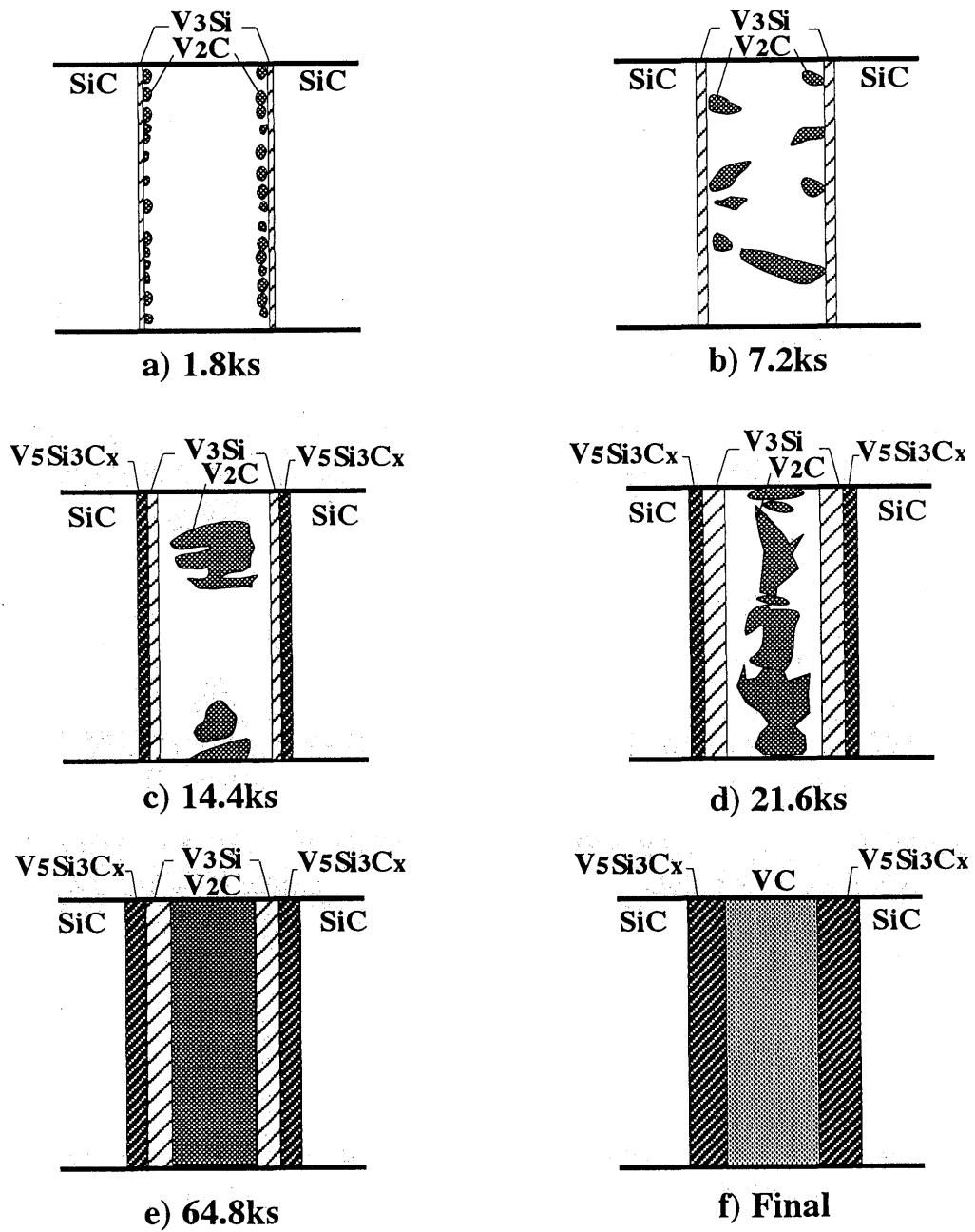


Fig. 12 Change in microstructure of the interface between SiC and V bonded at 1573 K for the bonding time from 1.8 ks to 64.8 ks.

4. Conclusions

The solid state bonding of SiC to SiC using V foil was conducted at the bonding conditions of 1373 to 1673K, 1.8 to 64.8ks and 30MPa under a vacuum below 1.33mPa. Interfacial reactions at the interface between SiC and V were studied using elemental analyses and X-ray diffraction analyses.

Reaction at the SiC/V interface was observed at the bonding temperature of 1573K for the bonding time at 1.8ks, two kinds of reaction phases are formed in the interface between SiC and V. The layer V_3Si phase is formed adjacent to SiC and granular V_2C is formed adjacent to the V. After bonding for 14.4ks at the bonding temperature of 1573K, the reaction zone adjacent to SiC consist of two reaction layers together with granular V_2C . The first layer is $V_5Si_3C_x$ and the second layer is V_3Si , and granular V_2C is grown in the V.

Thus, the complete diffusion path was established as SiC / $V_5Si_3C_x$ / V_3Si / V_2C / V_2C+V / V. At the bonding

time of 64.8ks and a temperature of 1573K, the central part of the V was completely, consumed and changed to V_2C or VC.

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