様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９　(共通)

科学研究費助成事業　　研究成果報告書

令和　 元 年　 ６ 月 ２０ 日現在

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課題番号：１６Ｋ０４９４７

研究課題名（和文）Si・C溶質が連続供給される溶剤金属からの改良TSSG法によるSiC溶液成長

研究課題名（英文）Solution growth of SiC by improved TSSG technique from metal solvent using SiC ceramics

研究代表者
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交付決定額（研究期間全体）：（直接経費）　　3,700,000円

研究成果の概要（和文）：炭化ケイ素（SiC）について、従来の溶液法とは異なり、Siを含まない金属溶液にSiCセラミックを溶解させ、SiおよびCが溶け出した溶融金属からの結晶成長を行う。溶融金属とSiおよびCの溶解度と溶解速度、4H-SiC結晶成長の安定性、再現性の観点から、この結晶成長に適した金属溶剤および結晶成長条件の最適化を試みた。
溶剤金属としてCrを選択することによりSiCのみを晶出し、溶質であるセラミックスをカーボンるつぼに接しない凹型にすることにより、溶剤中のSiおよびC組成を均一にでき、より厚いSiC結晶を成長できることを見出した。成長条件を改善することにより、より長尺なSiC結晶成長の可能性を示した。

研究成果の学術的意義や社会的意義
従来行われているTSSG法によるSiC溶液成長では、成長が進むにつれて溶液中のSiおよびC組成が変化するため、次第に同一条件下での結晶成長を維持できず、長尺の結晶を得ることができなかった。それに対して、本結晶成長方法において溶剤金属としてCrを選択することによりSiCのみを晶出でき、溶質であるセラミックスをカーボンるつぼに接しない凹型にすることにより、溶剤金属中のSi、C組成をほぼ等量の25mol%程度に一定にできることを示すことができた。これらの成果によりSiCの長尺化の可能性が示唆され、今後の成長条件改善により、同一の結晶成長条件下での高品質で安価なSiC単結晶成長の実現が期待される。

研究成果の概要（英文）：We examined solution growth of SiC from a Cr solvent without molten Si with the use of ceramic SiC feed and a carbon crucible as the SiC solute source. Cr metal was selected for the metal solvent, and we investigated the effects of cylindrical and concave of the ceramic SiC feed. Non-contact between the solution and carbon crucible was realized with the use of a concave ceramic, which maintained the Cr melt within a concavity, whereas the melt contacted with both the carbon crucible and ceramic for the cylindrical ceramic. The growth rate was about 16 times as high as that of the cylindrical ceramic. We found that C and Si concentrations in the residual Cr-based solution were almost the same for the concave ceramic, whereas the C concentration was high and graphite was observed in the solution from cylindrical ceramic. Therefore, we concluded that the use of Cr metal and concaved-shaped ceramic was suitable for the present improved solution growth of SiC.

研究分野：結晶成長

キーワード：炭化ケイ素　溶液成長　改良型TSSG法　セラミック　溶剤金属　溶質連続供給

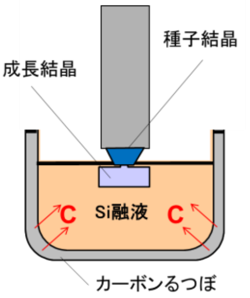
SiC

SiC

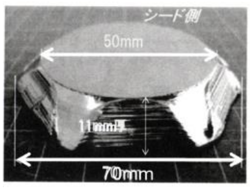
Top-Seeded Solution Growth (TSSG)

SiC

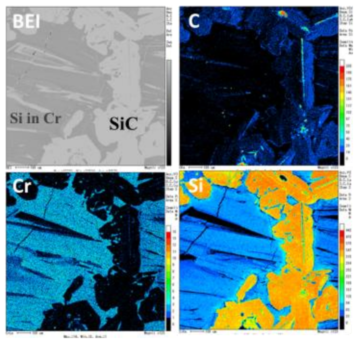
Kusunoki et al., J. Cryst. Growth (2013)



TSSG



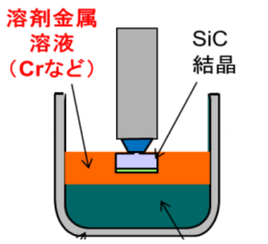
TSSG SiC



SiC Cr EPMA SiC Si C SiC

TSSG Si SiC SiC Cr Cr SiC Si Cr SiC Si C 20at% SiC SiC

SiC Si 85 SiC Si C SiC SiC SiC Si C 4H-SiC



(1) Cr Ti Ni Fe SiC Ni Fe SiC

(2) Cr Ti SiC

(3) 3 % 8 $ 2 6k 50mmSiC)B5)B6b2Ab0¦

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q Pc5 & Cr Ti Ni Fe b SiC N b P0Z P0Z0¦

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x0T8B_WZc 2000°C

SiC N 0 ASiC 3.14g/cm³b 1600 2100°C

(>)SiC P6×6Ì

@ (>)gW? Si \ C p5 P0Z (>)/%l 1200 2000°C

Cr Ti Ni Si KZ8 SiC N V_ Pc5 K

9×5 %0KX6KS 7KT KS 5 4P

0ZVdK 9Sb SiC N b55b3Q/eS5 K0•

KZ84b8g9×b 2E• SiC P0Z8

g/cm²í sec 5 Hb3Q/e

r SiC N b P0ZE00

SiC N Ab Kp_8K q [P0Z88

6 "Z SiC K p_ì/%0KS5 0M4M•

Qb7• SiC N 4E P0ZM/ Pc5 " P

0ZC8Kp2A0K)B9•

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Ar 7V¼ 1 5 %0M• q 0bWS Si C b P0Z4)

M6S_BH_4KS SiC)P/% 5 /8_K0O SiC

b)B6MV 5 g H28 T%K0%l@ 1500°C

Ni g Fe 5 K)%TKS%6bM QWS)

%Wb 4:KZM)b00b

(3)P/% 00/eB

28 %$ 20mm6k 10mm b SiC)B6MG% MS@£

3 SiC)@6K868cI)B6 b50e H28

_18K H29 5l$Qb0ZSub98/e

t 9%l5 & Cr Ti SiC)BT0MEb)B&

H28 s 1*4T%l 1500°C Cr Ti S SiC)

B/e B6MGKZq4: 4H b

SiC MCSu8o% c8rKP9×B6×FE3U

CSuT0 K)B6@bSu s

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6)c s 1£2)8pM•

u SiC P6×E8)B6b0¦

t CZ 2 Si)B6r_WZ8)B6bSub

b q4:%2b@M)9%0b† SiC P6×

4:K3) SiC P6b6X8Z0M•

v %$ 2 6k 50mmSiC)B2Ab0¦

t u 2 N s t]

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X8Zc X)z0M•S)pb5@

(b TOF-SIMS (0M4)0e

1_B 30 %$ 2 6k 50mm b 4H bME x

3) 100cm⁻²b SiC)B% M•

2,%EBY

(1) B 28 b8oBY

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P0Z0¦ /e SiC N Kpb P0ZE00\Pc5 "

& Cr Ni Fe SiC)B0KS

rN Pc5 † Fe KSœ SiC N P0ZKpb P0Z

@GWSì_ SiC N g)VKS Fe ?

SiC %Eb PcKZc:6•)1=KS

_ Pc5 † Ni KSœ SiC N b P0ZASW

KS Ni SiC)@ Ni-Si W

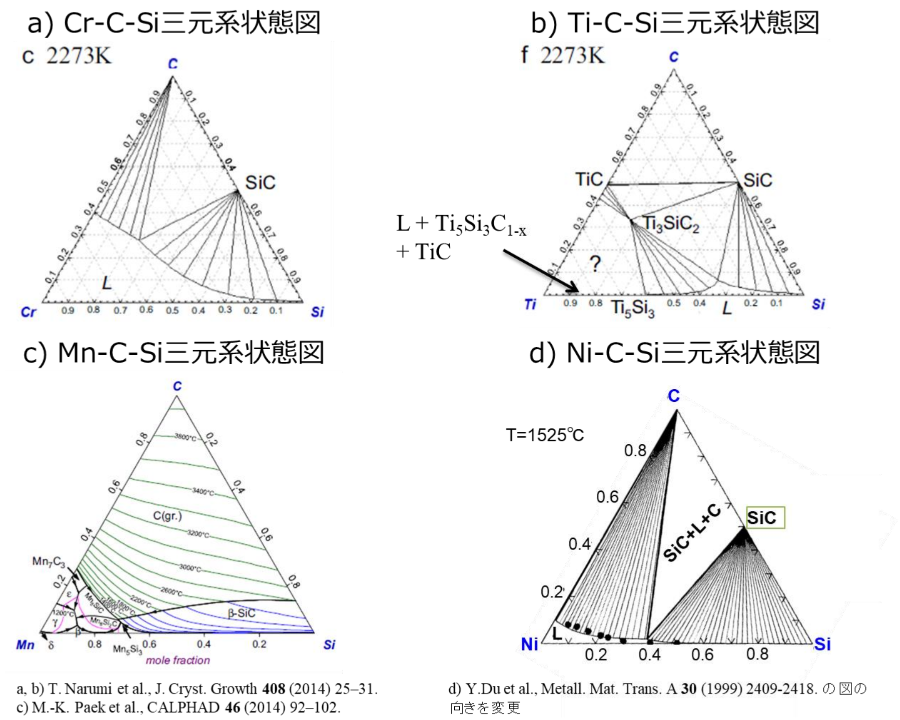
Z Ni v PcKZc:6KS

Pc5 KZ Cr Sœ N V_KS Cr ? SiC)A

SrS SiC)%W_ SiC)@6MGv8S6VFG SiC

b)B63 @ $QE Cr †Pc5 KZ•

Vb)ÝW 5 _gM Si C M& M: Pc5 bU(@W c%%ON θ
KSp[Cr @BON SiC _w[G@A•
%P5 KZ4:[G@



W 5 Si C M& M: 5 “ Cr, Ti, Mn, Ni U W

(2) B 29 bBÝ

Pc5 KZ c B 28 _4:[KS Cr KZ)B6, KSW 4 b W_Z)B6× K Pb9& N
κ r b2¥ 5-15mm PÄ 3-21¥ /cm b(V O Z)
B6KSQb)Ý W 6(a)b B6×_X8Z/0
B6b WS

W 6(b)cB6KS)/b
6M[•
B6KZ Py5 “
bT[g?
B6×/3gWZ8S Cr Py@
)_v3rZKS)•

P® 9KB6
K@ 4H B6K@
98 KCc 4H
SiC)B6MG@WSS
Sc98 4H M
B6KSB6WS

Cr Pc5 KZQKS)B Ä
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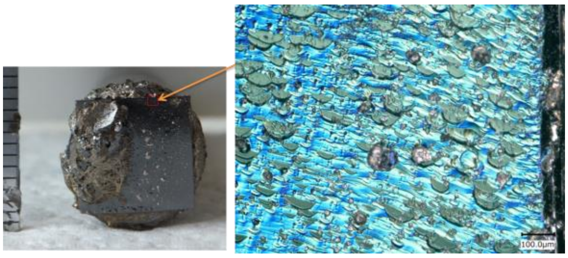
r S Pc5 KZ Al EKS SiC N gKp
P0KS N VKS Al SiC)cN b Al_4C_3
)WZ Al c Pc5 KZ[)1= ES

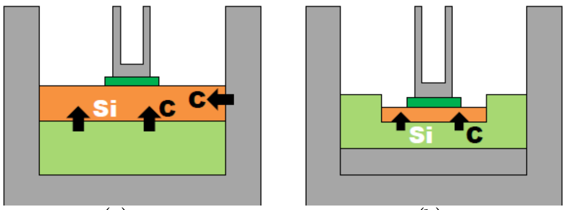


(a) (b)

6 (a) Cr (b)

(3) B 30 bBÝ

B 29 PyKZ4:G@
6G@S9×%15
6• Cr _PKZ P2A SiC Û
N bg9 Cr _
Al MG_B6b¹
B6Z8j_X
8ZKS

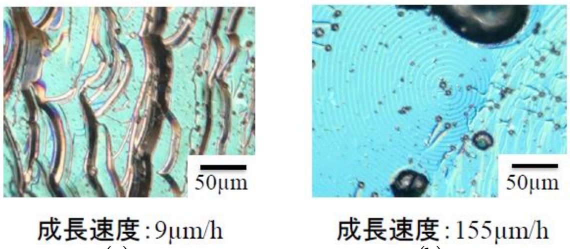


(a) (b)

7 (a) (b)
SiC

W 7 _gM SiC N

7(a)> K0K8 º&W 7(b)>b 2 8®X8Z9KS Qb)Ý W 8 _&M¦_Æs mZ$% @B6KB6⁄8c)Ð1B6×] 6G\&KS B6× EPMA _Kp_ÆgWS5 þb)B(@WSG• Xp 1 4# t(bN Ĥ P0Ž| ~Pypb B;A2s GM G(N Ĥ p5P0Ǩ



(a) (b)

8 (a) (b) SiC

SiC bB6×4:K Z8G@WS EPMA [KS Si C)Bv_ Si> C> Cr bU(g)W_ M• Q Ý S c C.. SiC _4t4G0AS M‰ Al MG_B6⁄8b K† 5 (b 1 b 0.1# m & ØDMG@ $MG@WS Al † 20mol KS Py Al-C BI€ SiC bB6 G&K 10mol% Py B6KS VbG Si 85 “Py_ SiC PB6 Al 92Aì AG0ÉKS TSSG 2c$ SiC Nq K Pc5 þb Si C)Bp5b 25mol% M_AG&K B6•5b SiC)b8KS STK6% KZ8S 5B6× %$ 2 gi_c NÒ b18WS

3 zÂ=e ¼

6 b

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2) u%$(* NÃ * ĐN , SiC P2_E t(b) SÑ b * " 47 G)B6Ý Ÿ , 2018 º 11 v .

3) 5eE * ĐN * P2Aj)% bgg OS Cr M Pyþ SiC PB6× * " 47 G)B6Ý * Ÿ , 2018 º 11 v .

4) ĐN , SiC PB6×E•Ppbt(b) B6 8Ž , B6 102 G%Ê , ‡ , 2018 º 3 v . 1n ‡

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7) %$(5eE ĐN 1¾ , Si_Cr_C g Si_Cr_M_C (M=Co, Mn) Py_ SiC PB6× , " 12 G 6%Ê , « , 2017 º 12 v .

8) 5eE , 9 , u%$(, , ĐN , , N‡ , N- , SiC PB

Cr)B_PMÞ6ÊŠ 8(Ælg%ÞÑb0Û ,
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9) 9※ , Ðe , u%$(, 5eÊE , C9× , ÊN, SiC P②_EÞ
t(ð P0Ž)2Ab6ð(ÐP0Ž(ÐP0Ž , 7Ê3ÊŠ
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19) 5eÊE , ÊN, Cr PyÊS SiC PÞ6×EÞ6⁄ 8Ê , ' 3 G
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