Environmental Barrier Coatings für SiC-basierte CMCs

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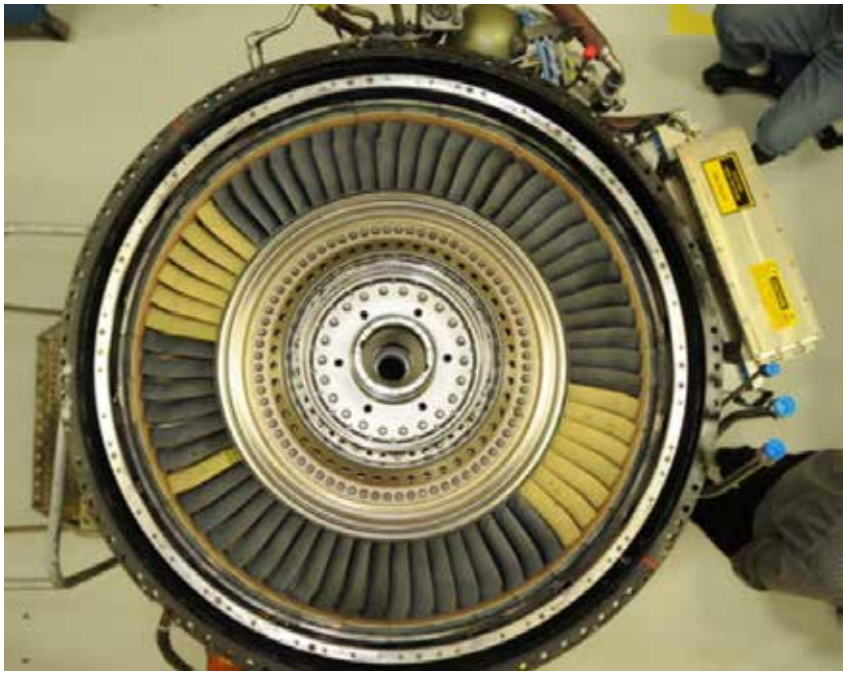
Zielbauteile: Heißgasführende Teile der Gasturbine

Static turbine shroud in CFM (GE – Snecma) LEAP engine; CMC based on coated SiC fibres and processed by LSI, grinded and protected with a thermal barrier coating



Turbine rotor made of CMC blades tested in a F414 jet engine; yellow blades are covered with EBC

Source: GE Aviation and CFM, May 15, 2015

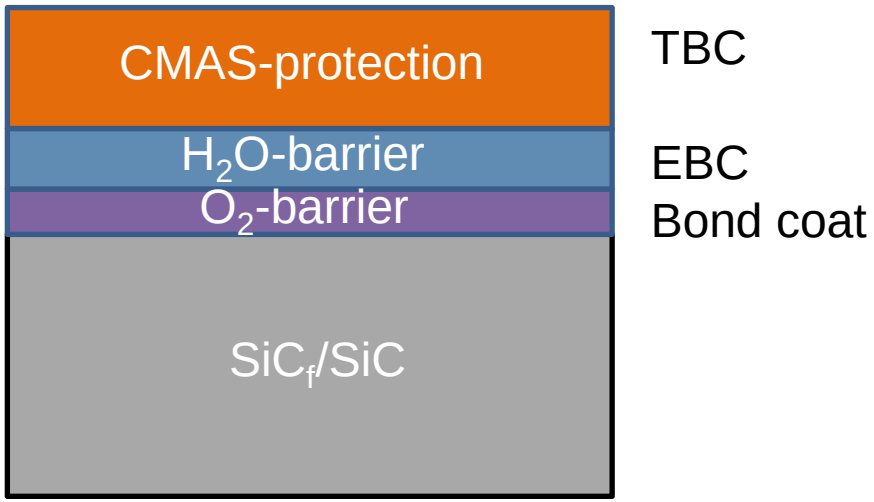
Anforderungen und Schichtaufbau von EBCs für SiC-basierte CMCs

Anforderungen an EBCs

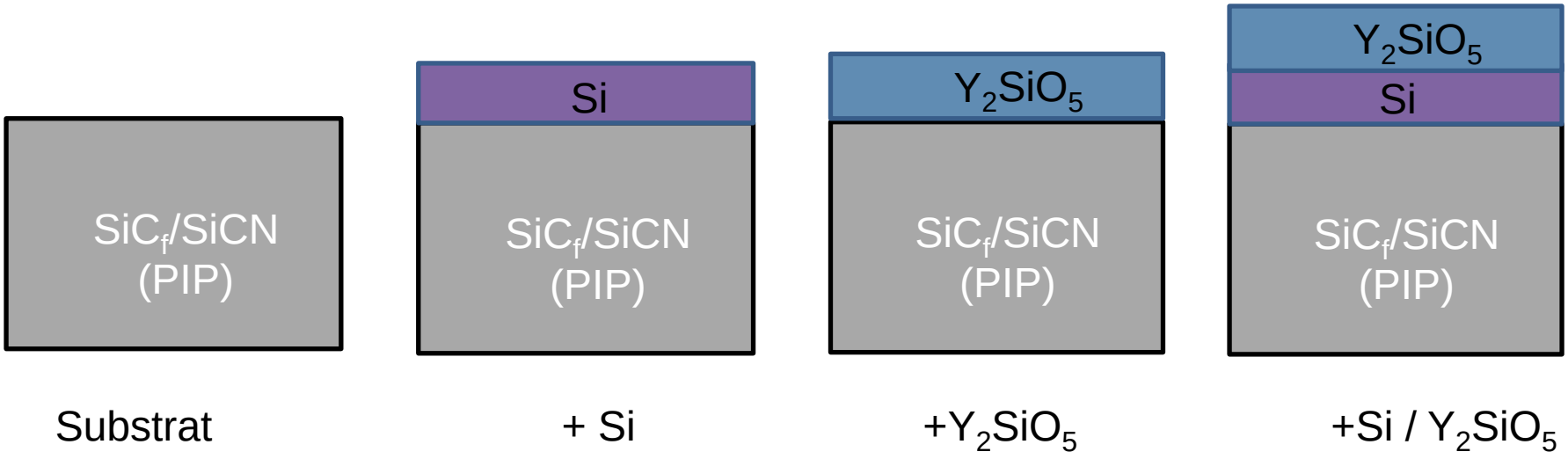
- Long term stability (phases, sintering)
- Low stresses (CTE, Young's module)
- Chemical compatibility
- Good adhesion

Schutz gegen:

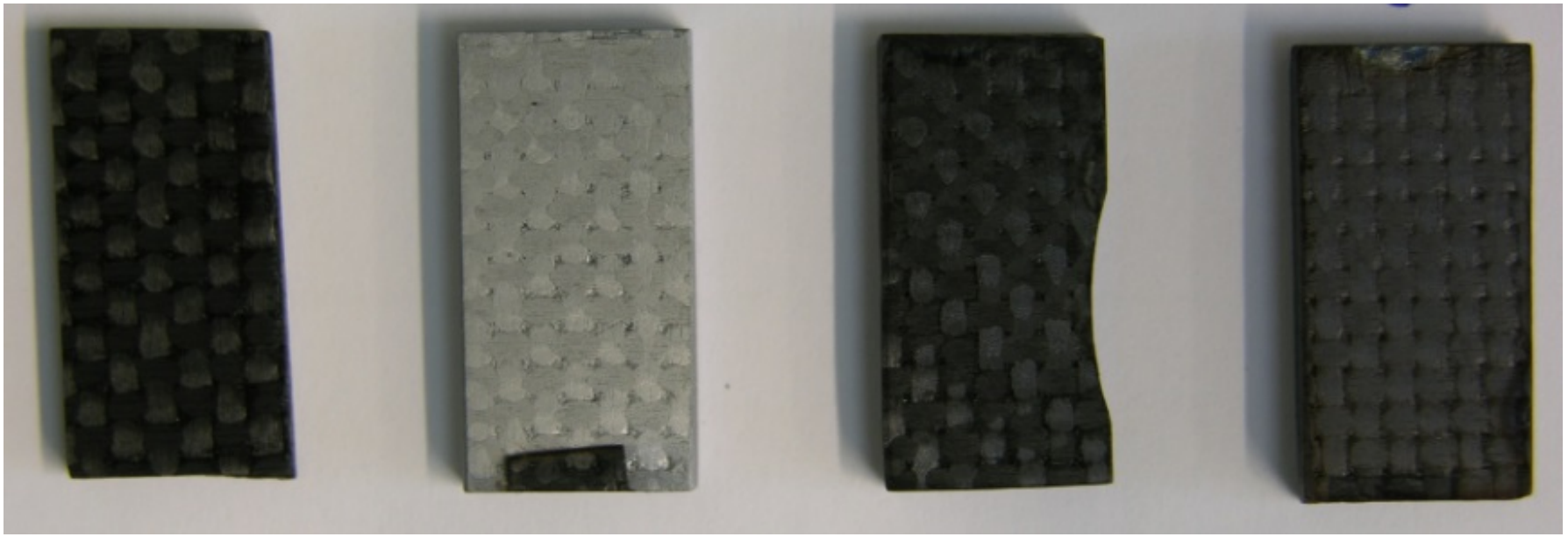
- Sauerstoff
- Strömenden Wasserdampf ($SiOH_4$ ò)
- Wärmeeintrag
- CMAS
- Korrosion
- Erosion / FOD



EBC Schichtsysteme

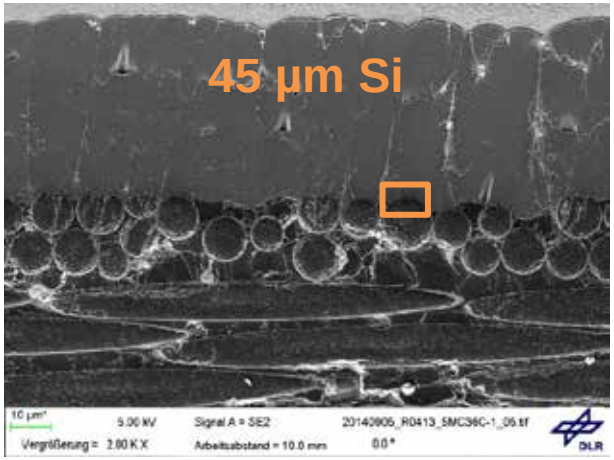


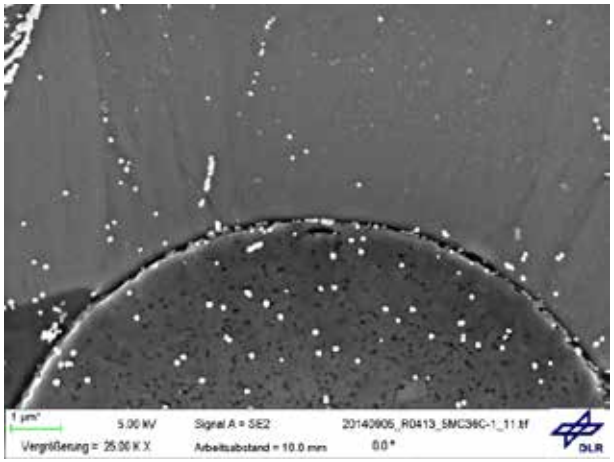
Substrat + Si +Y_2SiO_5 +Si / Y_2SiO_5



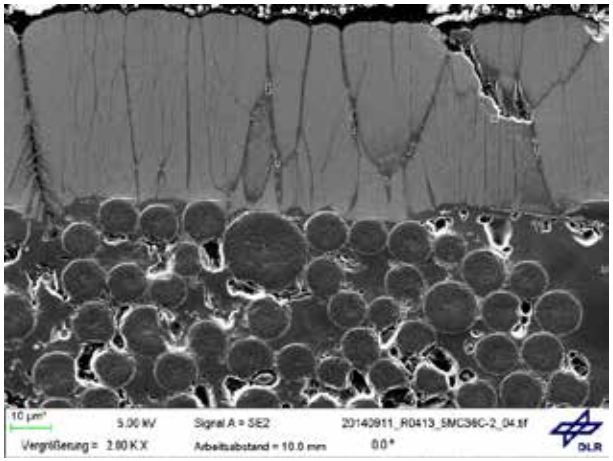
Silizium bond coat

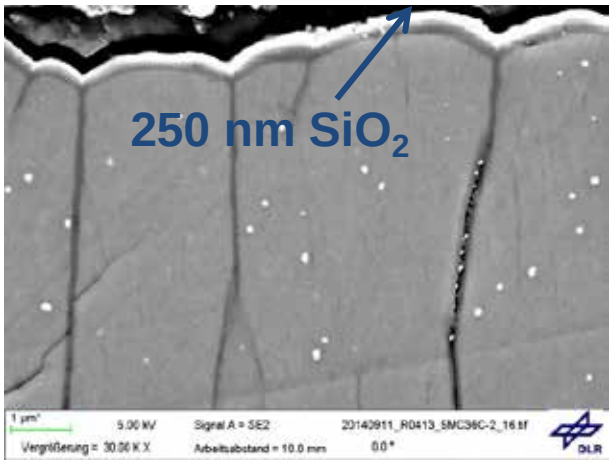
as coated





1200°C / 10h

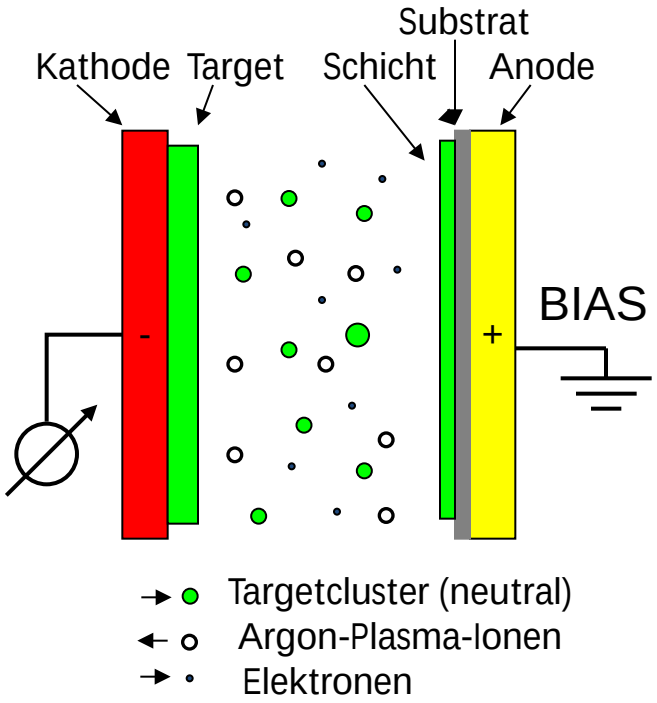


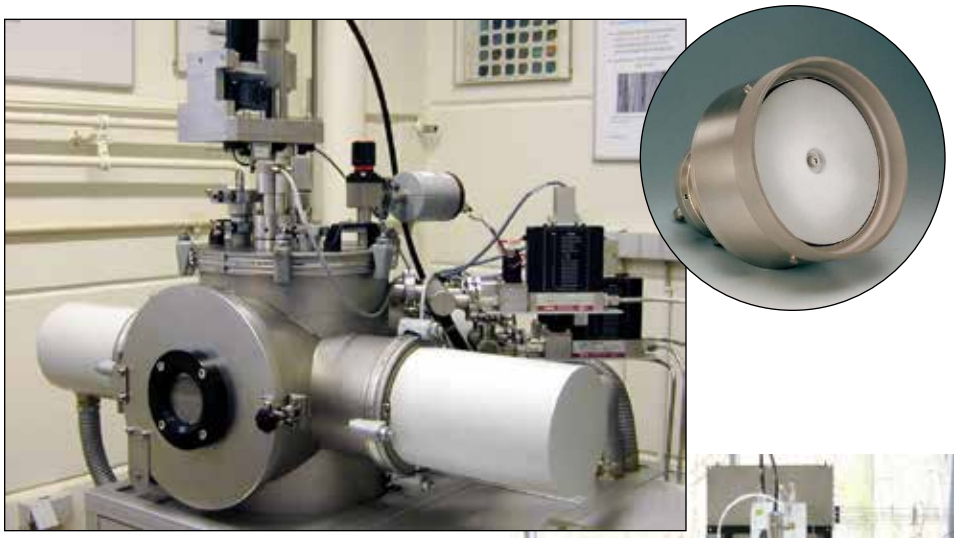


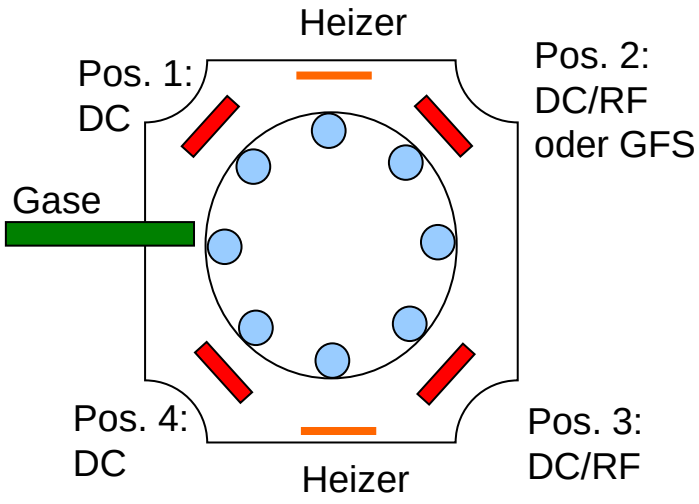
à **Parametervariation beim Magnetron-Sputtern zur Optimierung der Mikrostruktur**

Schichtherstellung: Magnetron-Sputtern

Funktionsprinzip Sputtern

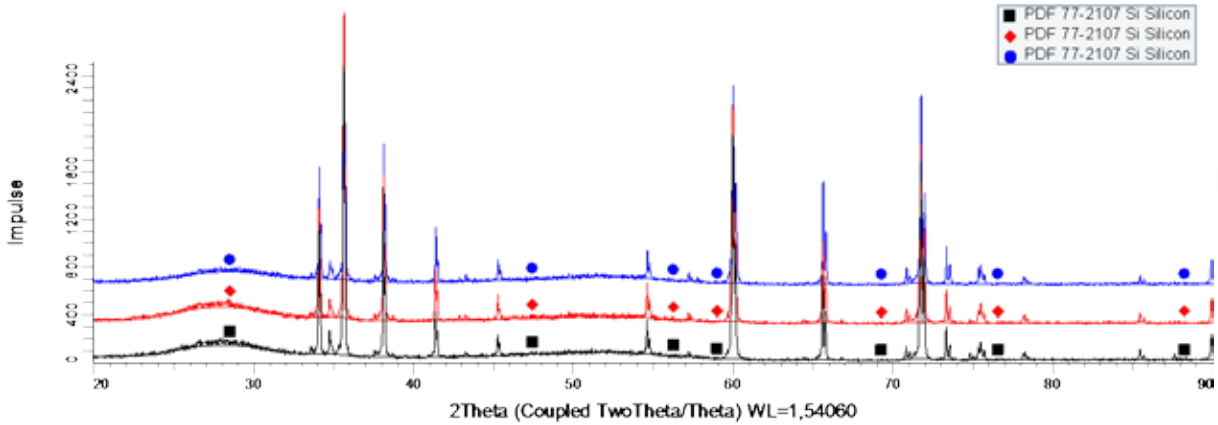






XRD Diffraktogramme von Si-Schichten vor und nach der Kristallisationsglühung für 30 Minuten bei 900°C an Luft

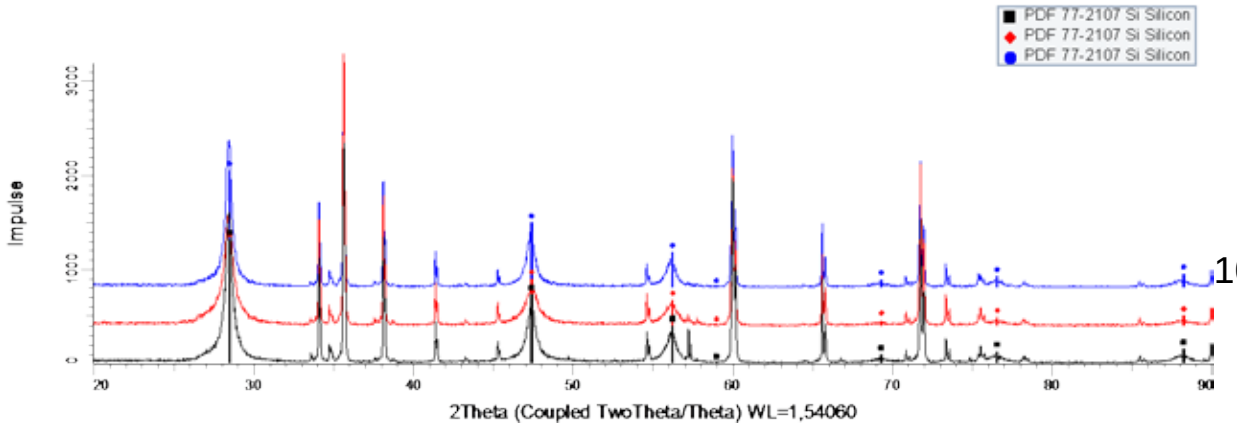
as coated



BIAS / Temperatur

100V / 120°C
0V / 400°C
0V / 120°C

geglüht

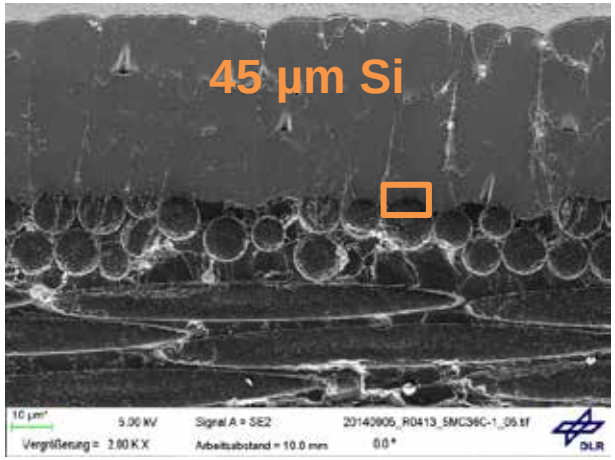


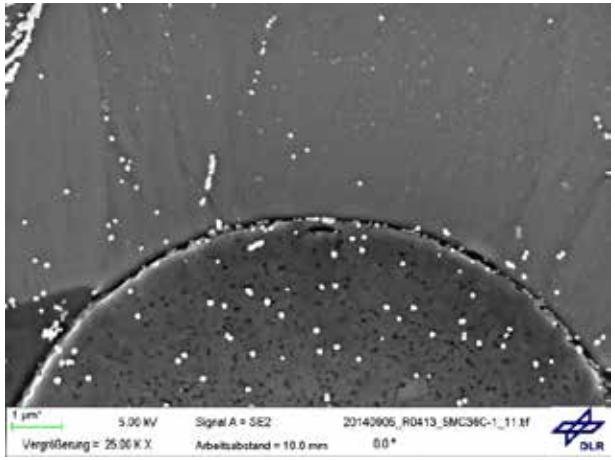
100V / 120°C
0V / 400°C
0V / 120°C

à **kein Einfluss der Beschichtungsparameter auf das Kristallisationsverhalten**

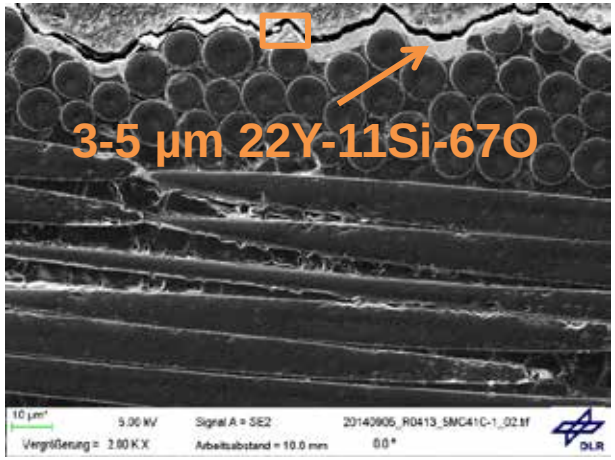
Querschliffe weiterer EBC-Varianten as coated

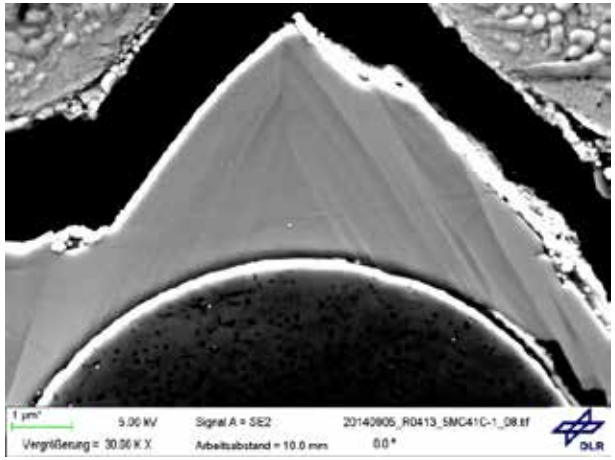
+Si



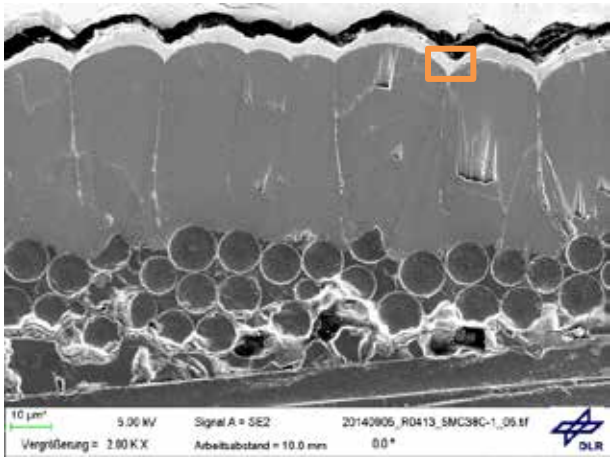


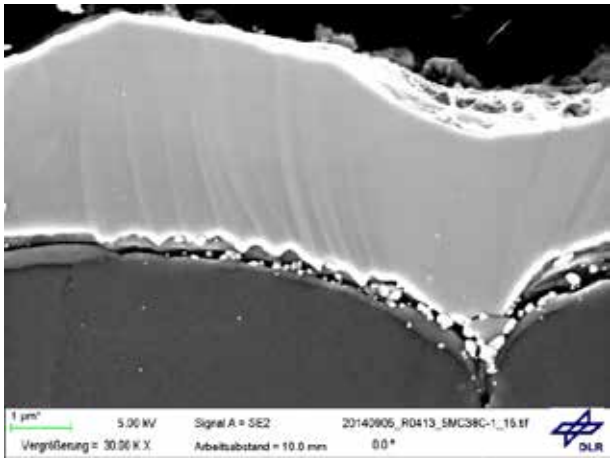
+Y_2SiO_5



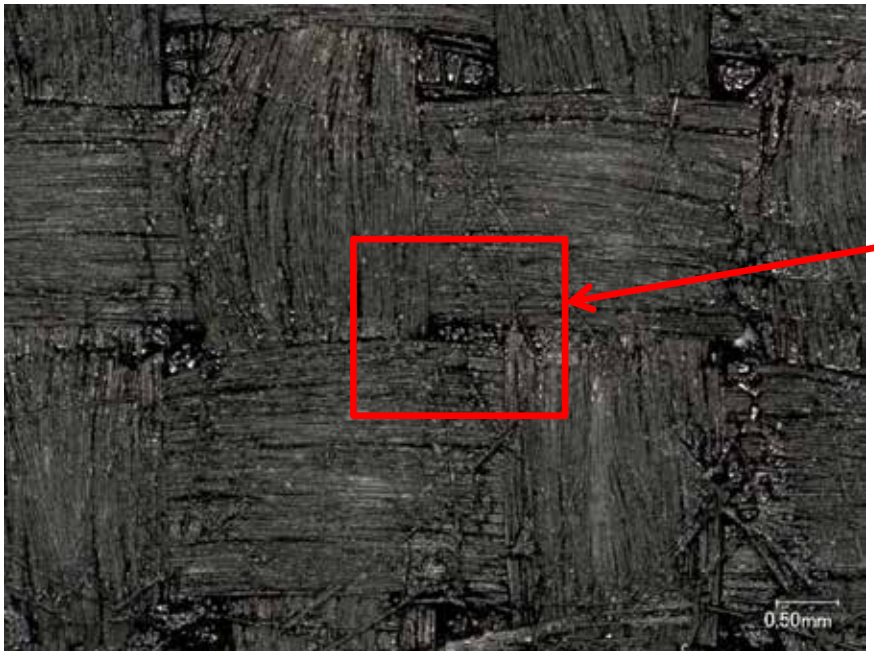


+Si / Y_2SiO_5





Oberflächenstruktur CMC - Material



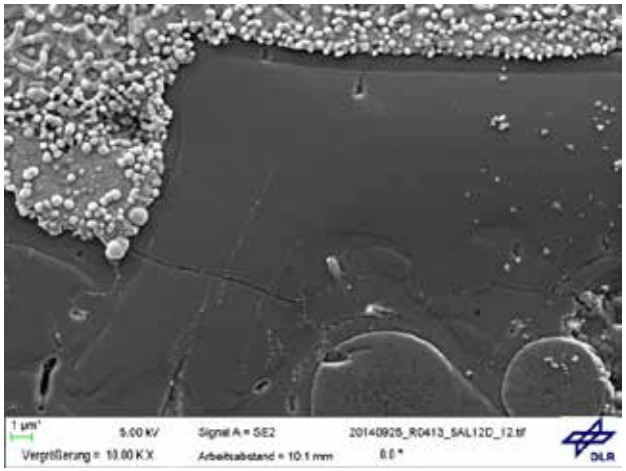
à **Raue Oberfläche mit Kreuzungsbereichen der Faserbündel**

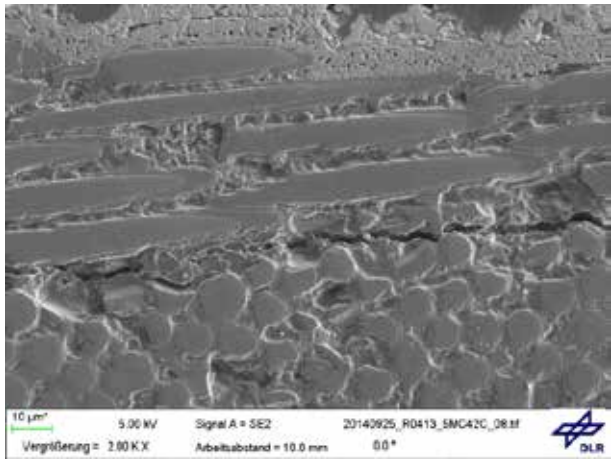
Nach Thermowechseltest bei 1200 °C für 100 h – Querschliff

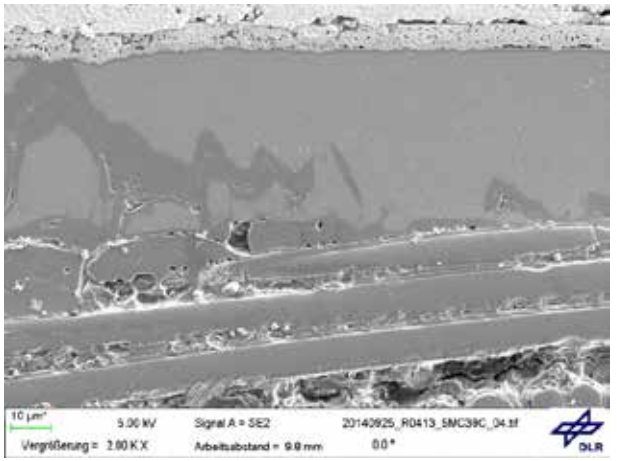
Substrat + Si

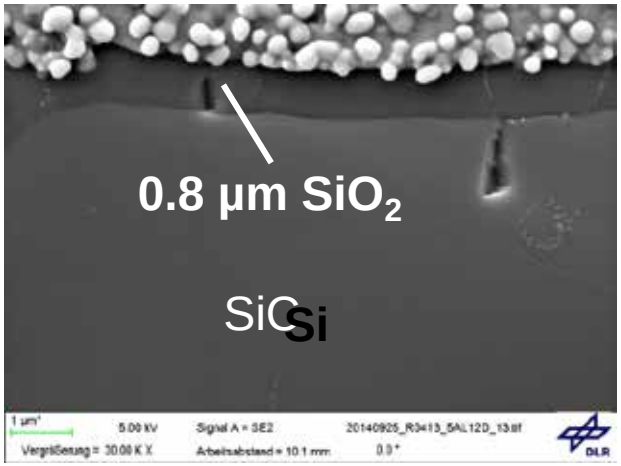
$+Y_2SiO_5$

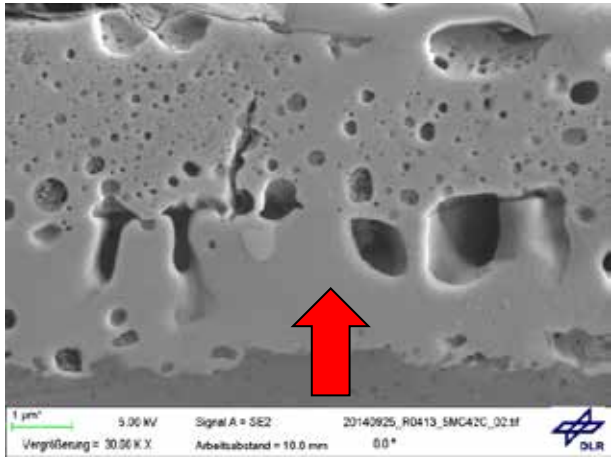
$+Si / Y_2SiO_5$

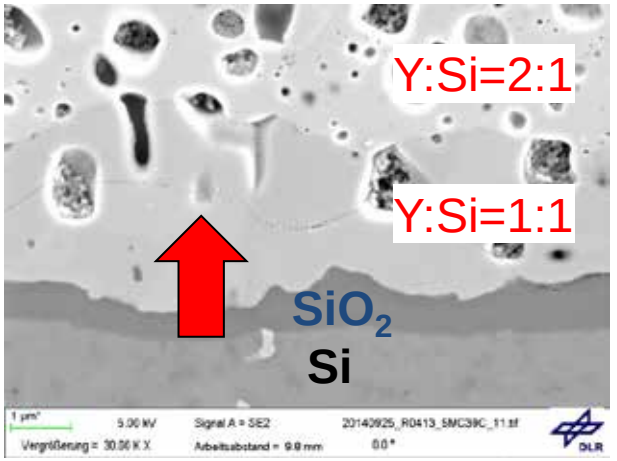






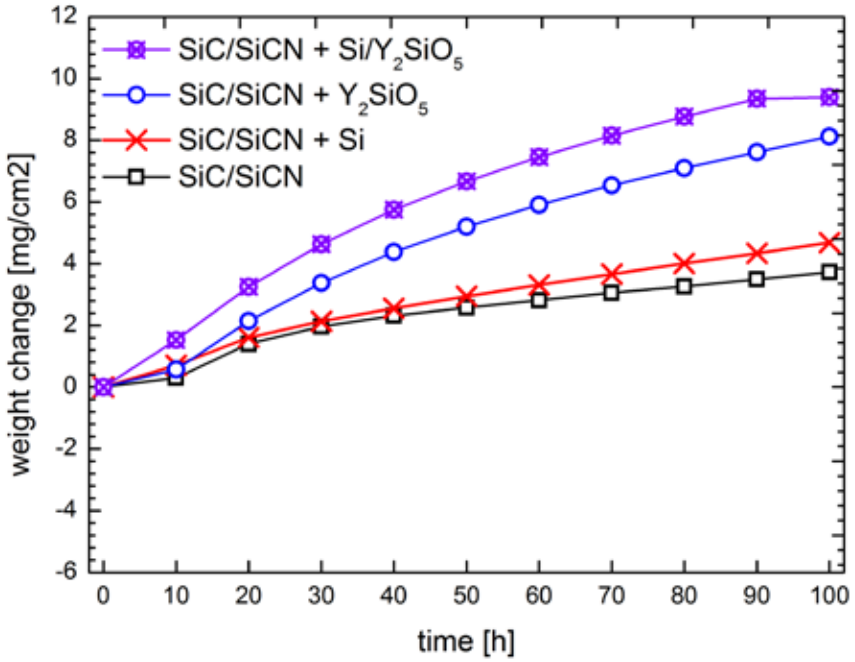






à **Reaktion des Y-Monosilikats Y_2SiO_5 mit SiO_2 zu Di-Silikat $Y_2Si_2O_7$**

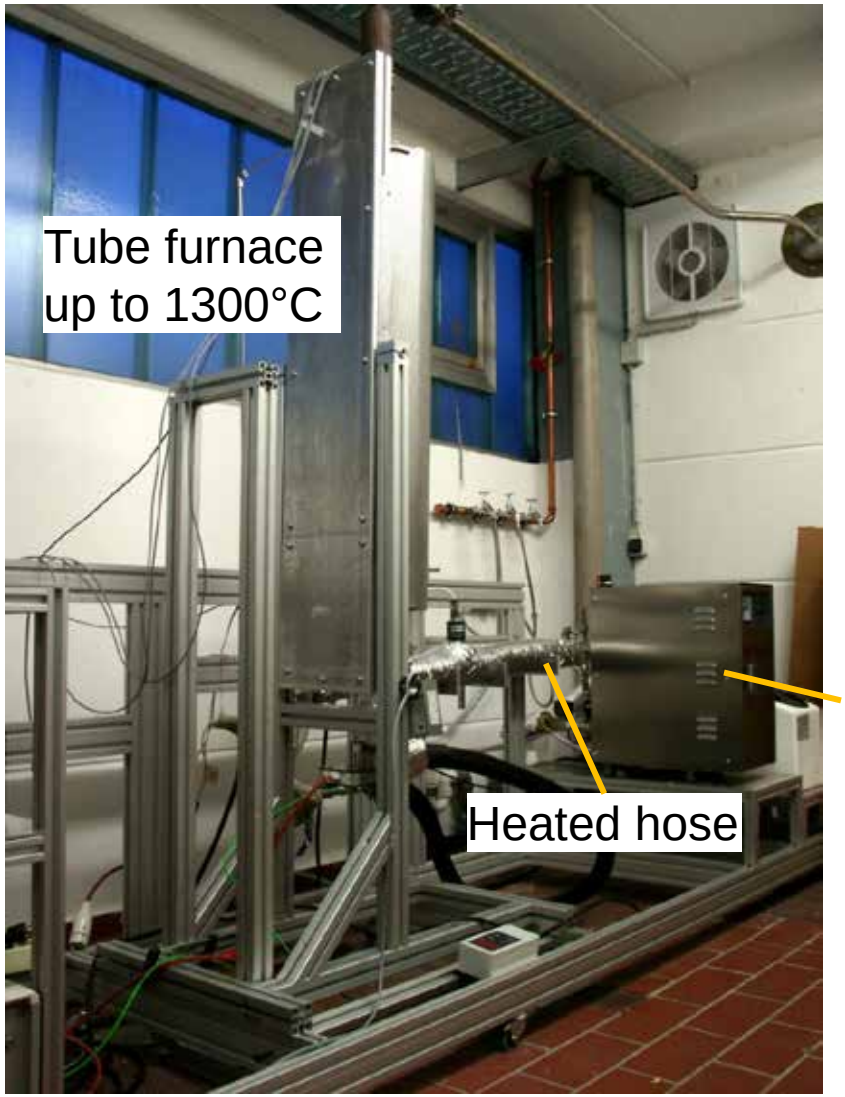
Nach Thermowechseltest bei 1200 °C



à **No spallation**
à **Parabolic oxidation**
à $k_p(Y_2SiO_5) = 2{,}08 * 10^{-8} \frac{kg^2}{m^4 s^2}$
à $k_p(Si/Y_2SiO_5) = 2{,}86 * 10^{-8} \frac{kg^2}{m^4 s^2}$

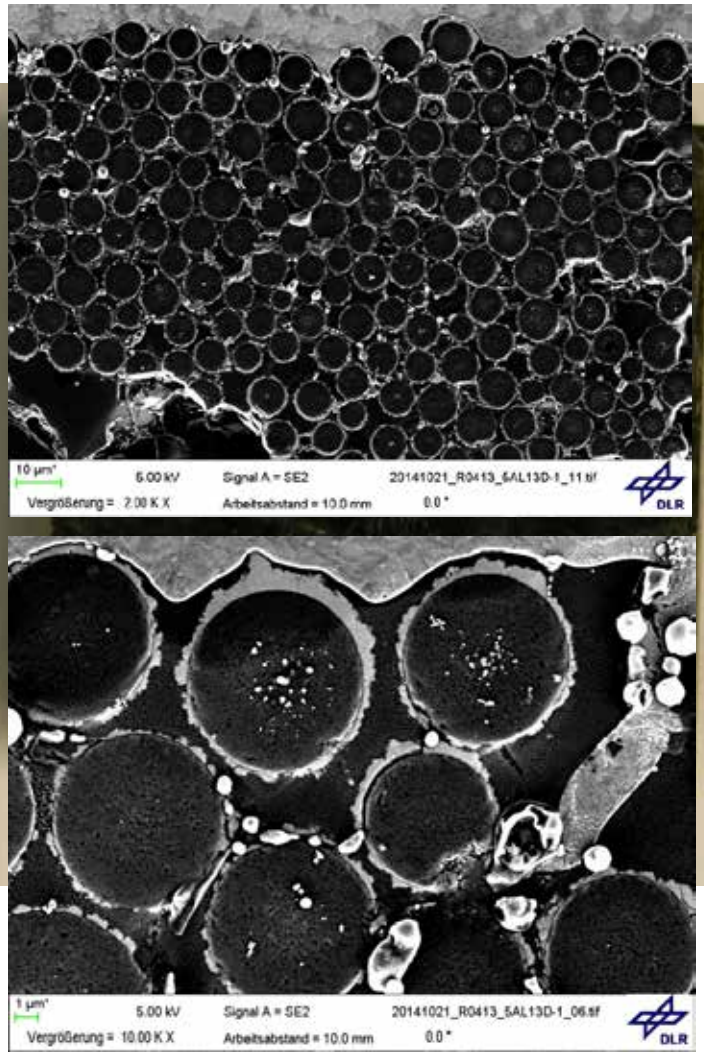
Wasserdampf-Korrosionsprüfstand

- steam flow rate approx. 10 m/s
- test consists of heating at 10 K/min, 1h hold time (both under water vapor), and cooling phase
- samples are faced at 45° to the vapor stream

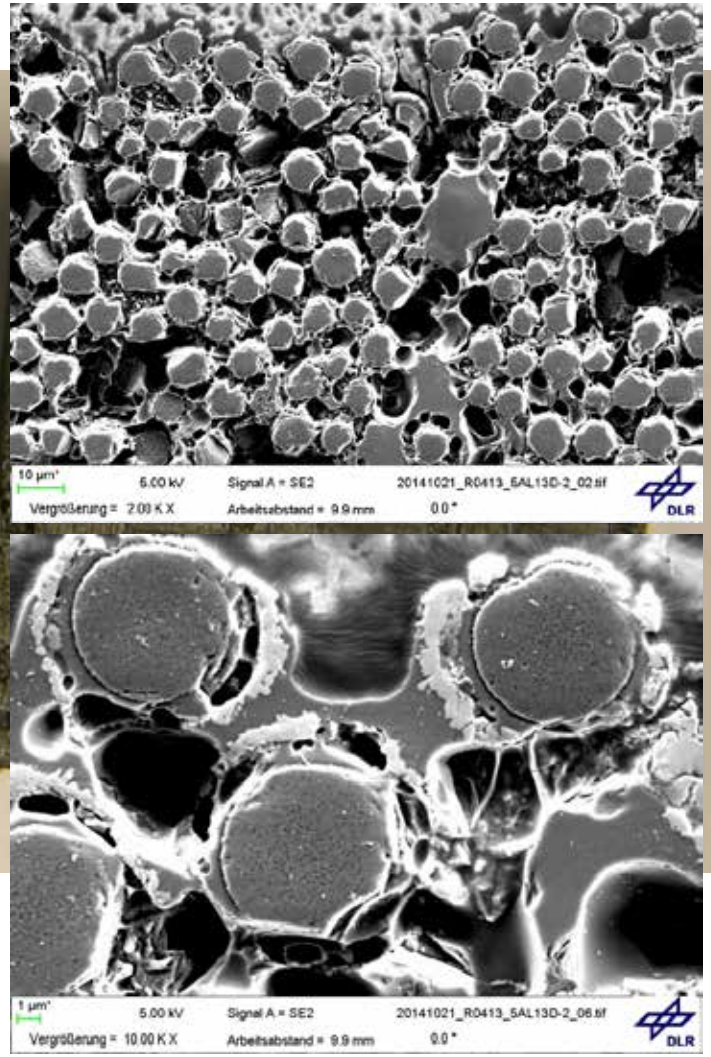


Korrosion in strömendem Wasserdampf 1200 °C / 1 h – SiC – SiC CMC

in air



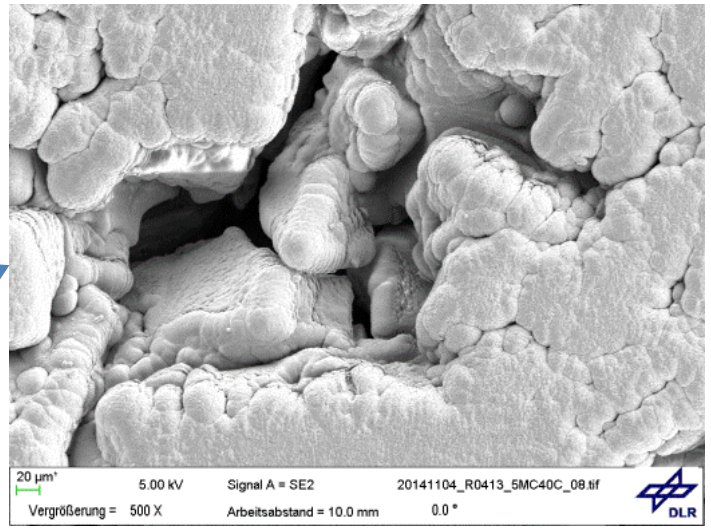
in water vapor



Korrosion in strömendem Wasserdampf 1200 °C / 1 h - Draufsicht

+Y_2SiO_5

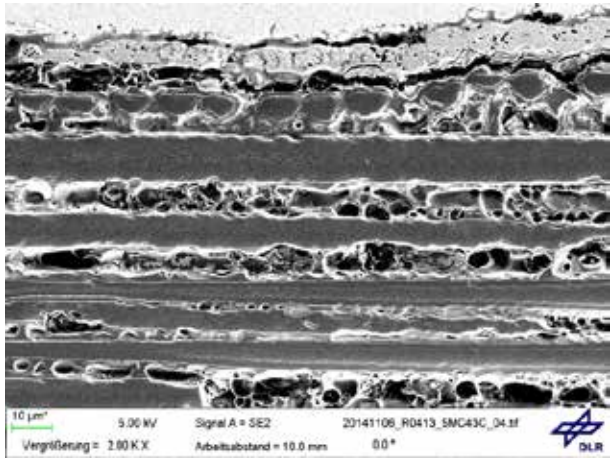
+Si / Y_2SiO_5



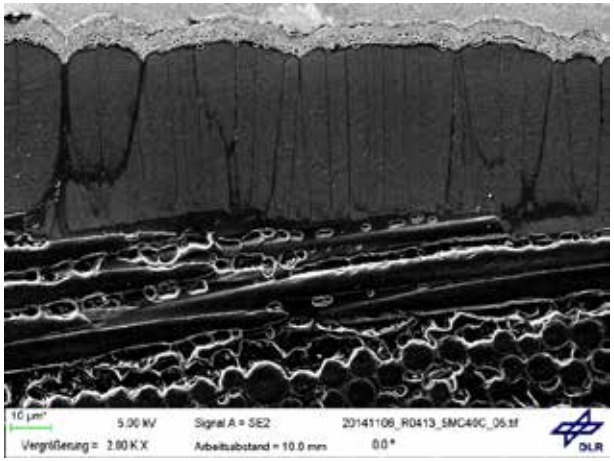
- à **Y-Silikate intakt**
- à **einige Risse im double-layer**
- à **leichter Korrosionsangriff an Faserkreuzungspunkten**

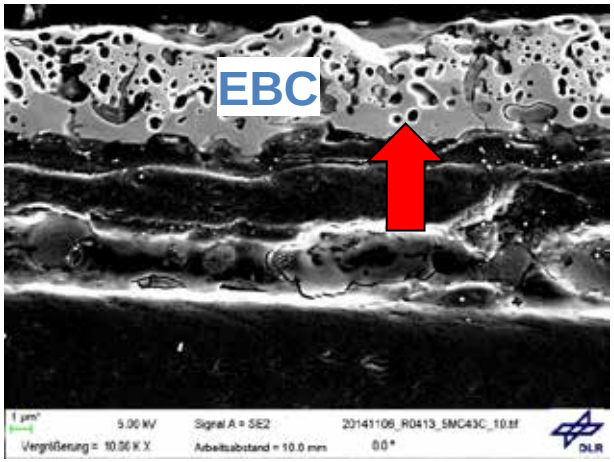
Korrosion in strömendem Wasserdampf 1200 °C / 1 h - Querschliff

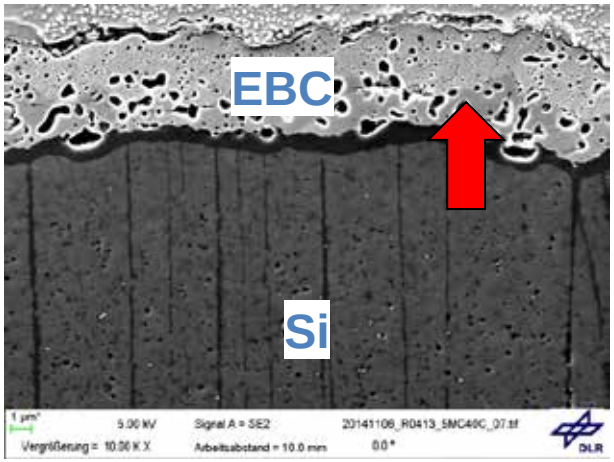
+Y_2SiO_5



+Si / Y_2SiO_5







- good adhesion of coatings
- pore formation in silicate, some interdiffusion
- limited oxidation along column boundaries in silicon
- oxide thickness under 1h water vapor similar to 100 h in air
- both coatings protect base material well

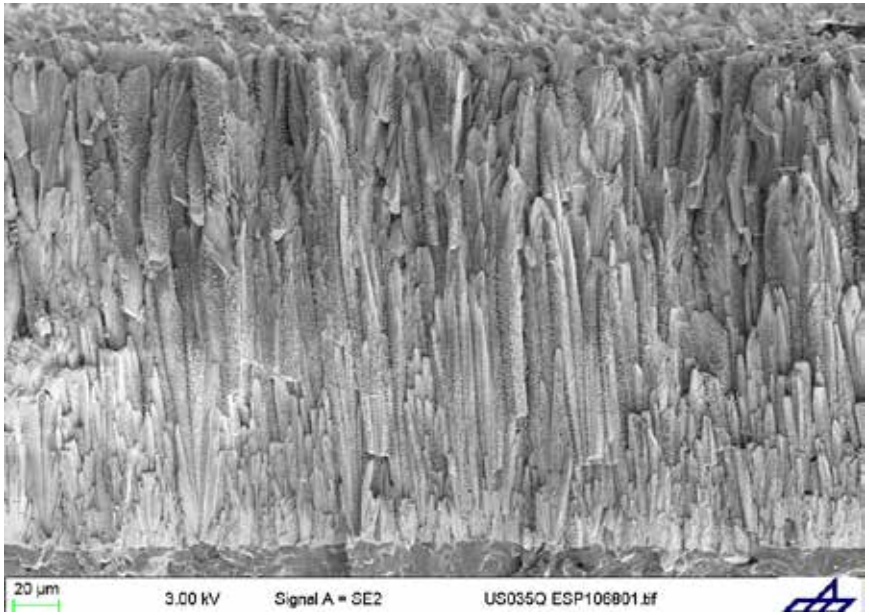
Zusammenfassung

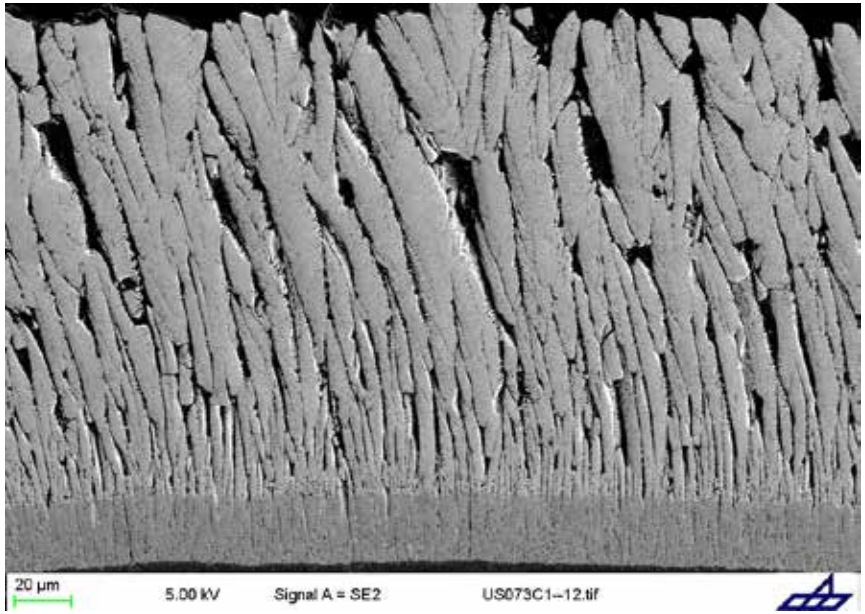
- **Gute Haftung der Magnetron-gesputterten EBCs auf CMCs**
- **Keine Abplatzungen während zyklischer Oxidation; parabolisches Oxidwachstum**
- **Geringe Diffusion von Si in Y_2SiO_5 und Bildung von $Y_2Si_2O_7$; keine Diffusion von Y**
- **Guter Schutz des CMC durch Y-Silikat im aggressiven Wasserdampftest**

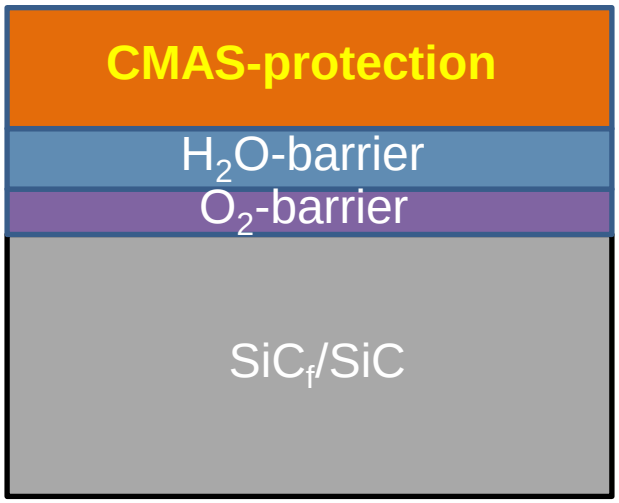
Ausblick auf geplante Arbeiten

- **Test der modifizierten Mikrostrukturen der Si bond coats**
- **Zusätzlicher CMAS-Schutz**
- **Dicke Multilayer-Silikate für verbesserte Schutzwirkung und Schadenstoleranz**
- **Test im Temperaturgradienten**

Schutz von EBCs gegen CMAS: z.B. $Gd_2Zr_2O_7$

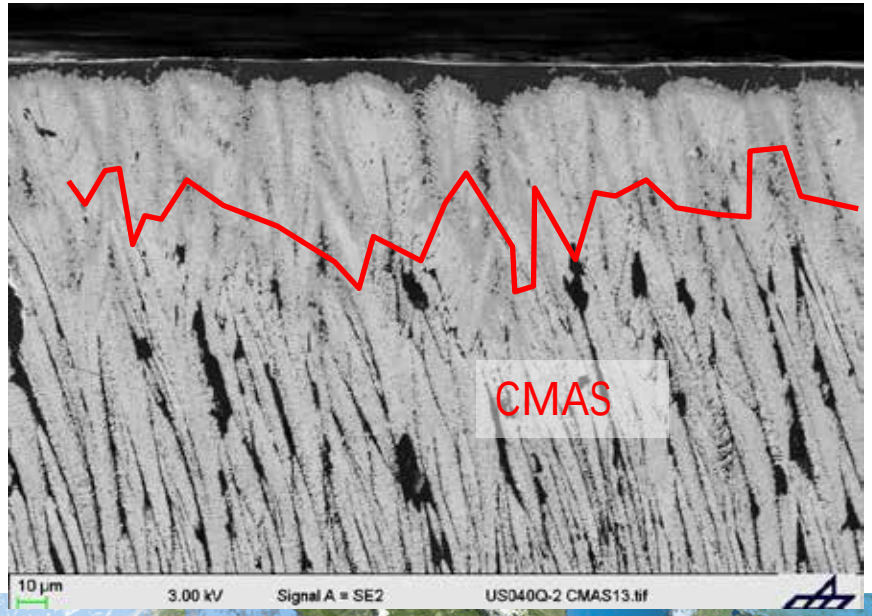




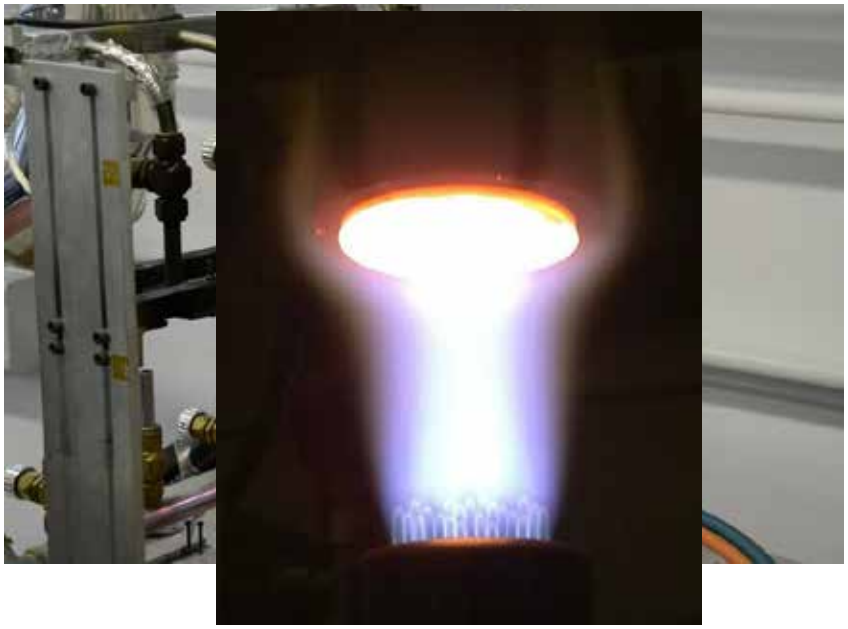


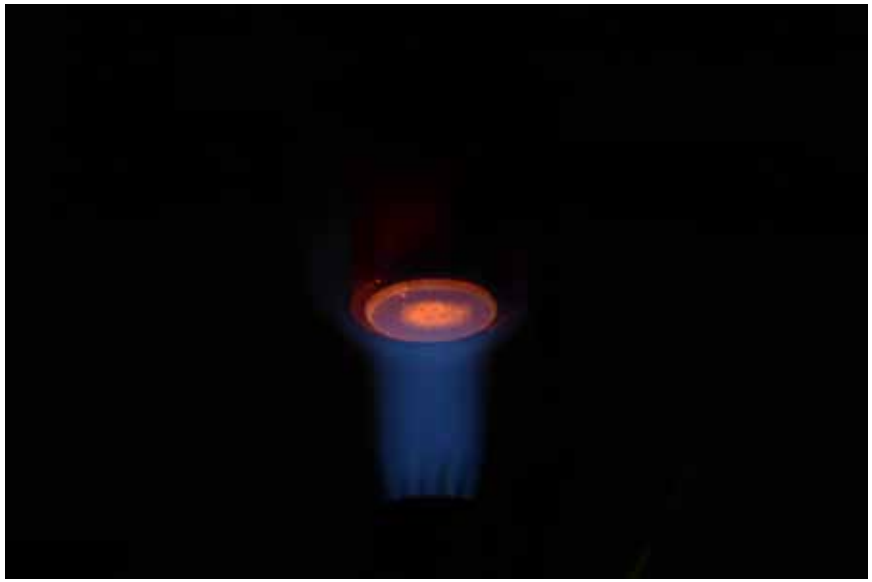
TBC

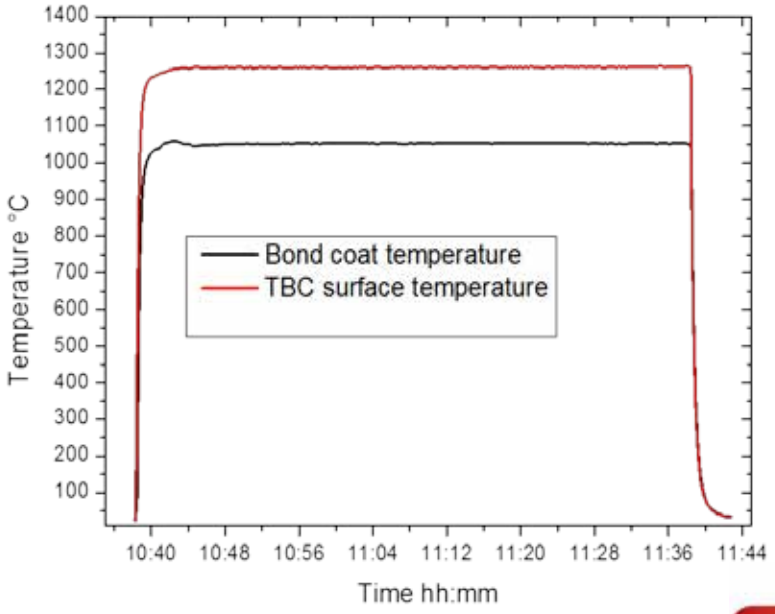
EBC
Bond coat



Gradienten-Testrig







- à **realer Temperaturgradient über EBC oder TBC**
- à **Gasatmosphäre mit Wasserdampf**
- à **Tests mit partieller CMAS-Infiltration wie auf Triebwerks-Bauteilen**