MATERIALS FOR FUSION APPLICATIONS

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A. SUPERCONDUCTING TAPES AND WIRE FOR HIGH MAGNETIC FIELD APPLICATIONS

- Development of YBCO superconducting coated conductors for fusion applications
- Development of Unreacted Multifilamentary Strands for the Fabrication of Nb3Al Superconducting Conductors for High Field Applications

B. BRAZING ALLOYS

- Brazing Alloys for SiC/ SiCf Composites and J oints for Irradiation
- Silver-Free Brazing Alloys for Be

C. ELECTRICAL CHARACTERIZATION OF SiC/SiCf COMPOSITES

- Measurement of electrical resistivity of 2D and 3D SiC/ SiCf composites in the temperature range from RT to 1173K
Intrinsic YBCO advantages
• high critical temperature, $T_c$ (93K) and critical field $H_c$ ($\approx$40T)
• highest critical current density at 4.2 K
• high irreversibility line

Critical current versus magnetic field for some used superconductors (presented data are at 4.2K, unless otherwise stated)
INTRINSIC DRAWBACKS OF YBCO

- High degree of anisotropy: \( \gamma = \frac{m_c^*}{m_{ab}^*} \approx 5; \quad \lambda_{ab} = 3nm \quad \lambda_c = 0.5nm \)

- Complicated fabrication technologies specific for ceramic materials

Critical current density vs. disorientation angle
Between two adjacent grains (D. Dimos et al, Phys Rev. Lett 61, 219 (1988))

Crystalline lattice of YBCO
Concept of coated conductors

• the metallic substrate has a sharp cub texture, developed by a thermo-mechanical process

• both the YBCO film and the buffer layer architecture are epitaxially grown

• the thickness of the metallic substrate and the YBCO film is 100 μm and 2 μm, respectively
I. Fabrication of biaxially textured substrates

- The Ni based alloys were prepared in an Ar plasma furnace.
- The samples were cold rolled to the final thickness of 50 microns.
- [100](100) cube texture was developed by a recrystallization heat treatment at 900 °C for 4 hours in high vacuum (10⁻⁷ torr).

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D=97 % ; ε=3.6
Optical image of the Ni-V tape surface after the controlled oxidation process

The same image in a black-white representation

Morphological properties of Ni-V and Ni-W tapes after recrystallization

Ni<sub>89</sub>V<sub>11</sub>

Ni<sub>95</sub>W<sub>5</sub>
EBSD orientation maps with respect to the normal direction for Ni-V and Ni-W substrates. The area of interest has been subdivided through a square grid, with a resulting pixel area of 7.23 µm². The red area refers to cubic grains, while the blue area refers to twins (see colors in the standard triangle). Black spots represent the unsolved points, e.g. grain boundaries.

EBSD (100) pole figures refer to the sampled area. The sharp and well developed {100} <001> cube texture is evident.
Grain boundary misorientation distribution for Ni-V and Ni-W.

Misorientations below 2.5 degrees are not shown. The twinned grains generate the high angle (60°) misoriented grain boundaries. The fraction of 60° misoriented grain boundaries is 13.4% for Ni-V, while for Ni-W it is 2.4%

Ni-V

Ni-W
Percolation maps along the rolling direction for Ni-V and Ni-W substrates. In this representation the grains misoriented from their neighbors by an angle less than 6° are colored in green. The Ni-W substrate has a percolation area greater than that corresponding to the Ni-V substrate. Mainly, this is associated with the higher fraction of twinned grains present in the Ni-V substrates.
Ni based tapes show:

• sharp cube texture and good morphology

• lower Curie temperature with respect to pure Ni

• good oxidation resistance

• high mechanical strength

• the Ni based substrates are appropriate for further buffer layer and YBCO epitaxial deposition
II. Buffer layer deposition

The following buffer layer architectures have been tested:

• Ni-V/NiO/CeO2
• Ni-W/CeO2
• Ni-W/CeO2/YSZ/CeO2
• Ni-W/Pd/CeO2/YSZ/CeO2
• Ni-W/Pd/CeO2/YSZ/CeO2

The best results were obtained for the YBCO film deposited on the Ni-W/Pd/CeO2/YSZ/CeO2 template.

SEM cross section through the buffer layer architecture CeO2/YSZ/CeO2/YBCO
III. YBCO film deposition and properties

A. Structural properties

Epitaxial relationship:

\[[100]\text{Ni-W} \parallel [110]\text{YSZ} \parallel [110]\text{CeO}_2 \parallel [100]\text{YBCO}\]

\(\omega\)-scan of the (002)Ni-W, (002)YSZ, (002)CeO2 and (005)YBCO peaks

\(\phi\)-scans of (113)YBCO, (111)CeO2, (111)YSZ and (111)Ni-W peaks.
B. Morphological and superconducting properties of YBCO film

SEM cross section of CeO2/YSZ/CeO2/YBCO

Magnetic field dependence of the critical current density for Ni-W/CeO2/YSZ/CeO2/YBCO

Critical current density $J_c$ (A/cm$^2$)

Magnetic field $\mu_0 H(T)$

$T=77$ K

H//c

Ni-W/CeO2/YSZ/CeO2/YBCO

SrTiO$_3$

Ni W 3

Ni V 5

Ni V 11
Development of chemical deposition methods for the buffer layer and the YBCO film

Precursor chemistry: trifluoroacetates (TFA) for YBCO

Deposition: spinning

Epitaxial growth: thermal treatment under controlled atmosphere

Properties:

YBCO/STO

YBCO/ CeO2/YSZ/CeO2/Pd/Ni-W
Critical current density versus magnetic field at 77 K for the YBCO film deposited by chemical TFA-MOD methods

Conclusions

- for both buffer layer and the YBCO film the chemical methods permit the deposition of epitaxial films with good structural, morphological and superconducting properties
- the chemical methods allow the up-scaling of the deposition process
B. Brazing Alloys for SiC/SiCf Composites and Joints for Irradiation

1. Preparation of eutectic alloys:

The Si-Ti and Si-Cr eutectic alloys were prepared in an Ar plasma furnace. The as obtained alloys were remelted several times in an high pressure e-beam to obtain a fine eutectic microstructure.

2. Microstructure of eutectic alloys

Light regions represent the Si$_2$Ti intermetallic compound while the dark regions represent pure Si.
3. Manufacture of the SiC/SiCf junctions

The junctions were heated at a rate of 10 °C/min at 20 °C above the eutectic temperature, kept at this temperature for 5 min and then cooled down to room temperature at a rate of 20 °C/min.

Cross section of the junctions

SEM cross section of the junction brazed with Si-Ti alloy

High magnification cross section

- Si
- SiC matrix
- fibre
- Si$_2$Ti
High resolution microscopy of the junction cross-section

- Si
- Si$_2$Ti
- SiC matrix

Scale bars: 3 µm and 5 nm
Si-L$_{23}$ edge

C-K edge

50 nm

SiC

Si

interface SiC+Si

102 eV 105 eV

b)

SiC

Si

50 nm

c)
Nanochemistry of the junctions

(a) Graph showing the Si-L\textsubscript{23} edge, C-K edge, and Ti-L\textsubscript{23} edge with energy loss values 103 eV and 105 eV.

(b) Image of the SiC+Si\textsubscript{2}Ti interface with a 50 nm thickness.

(c) Graph displaying CCD counts x 1000 for Si\textsubscript{2}Ti, SiC+Si\textsubscript{2}Ti, interface, Si\textsubscript{2}Ti, and SiC layers.
Mechanical testing

Shear strength 85 MPa
Conclusions

- eutectic Si-16Ti and Si-18Cr alloys are suitable for joining SiC/SiCf composites.
- the joints investigated did not show any defects in the brazing layer
- no interdiffusion or formation of additional phases was observed
- both Si-16Ti and Si-18Cr joints led to the conclusion that direct chemical bonds are responsible for the adhesion with the SiC/SiCf composites.
- the shear tests of the joints of SiCf/SiC composites exhibit remarkable values of the bonding strength up to 140 MPa).
C. Measurement of the electrical resistivity of unirradiated SiC/SiC composites

Temperature dependence of electrical resistance for SiC/SiCf composites