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Development of fusion technology for DEMO in Forschungszentrum Karlsruhe

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Abstract

The Forschungszentrum Karlsruhe develops for more than 20 years fusion technologies and structural materials for ITER and ultimately for DEMO. While the technologies developed for ITER have reached some maturity, although not yet completed, the technologies and structural materials for DEMO need substantial progress before such a commercial prototype fusion reactor can be built. The main advances required beyond the technologies already developed for ITER are: the development of high temperature superconducting coils, a He or liquid metal cooled breeding blanket, a He-cooled divertor and the integration of the "In Vessel" components into a DEMO (Tokamak) reactor (a complex design task). In addition the development of suitable structural materials for the blanket and the divertor is an urgent task. These structural materials have to be of a low activation kind (decay to low activation level within ∼100 years) and have to achieve a suitable lifetime (∼5 years, i.e. ∼150 dpa) when used for DEMO blankets and divertor and when considering the large neutron affluence in DEMO. In all these fields the Forschungszentrum Karlsruhe is very active and in many cases a world leader.

Keywords: DEMO; Technology; Magnets; Blanket; Divertor; Materials

1. Introduction

During the last decade the physics and the technology to construct a "Next Step" machine like ITER were developed in a world wide effort. The Forschungszentrum Karlsruhe (FZK) has significantly contributed to these developments and has thus gained a world leadership in several fusion technology areas. Since the beginning of this century it became clear in the fusion community worldwide and in particular in Europe, that to built and operate ITER and not to develop in parallel with a substantial effort technologies and structural materials suitable for a demonstration fusion reactor (DEMO) would significantly delay the introduction of commercial fusion energy. Therefore during the last ∼5 years the effort in these areas was increased, in particular in the EU, where a so-called "Fast Track"

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scenario for the introduction of commercial fusion energy was defined. This Fast Track scenario is now a very important pillar of the EU DEMO related fusion technology program and FZK is one of the leading laboratories for developing the relevant technologies and structural materials suitable for the DEMO "In Vessel" components.

Considering that most of the technologies developed for ITER will be relevant and used for DEMO and considering also that ITER is already a reactor class machine there are only a few but very important technological developments missing. These are (i) the development of high temperature superconducting (HTS) coils, (ii) the development of tritium breeding blankets (He or liquid metal cooled with high exit temperatures, e.g. 550–750 °C), (iii) a He-cooled divertor which can withstand up to 15 MW/m^2 peak heatfluxes, and (iv) structural materials for the blanket and the divertor, i.e. a low activation steel and W alloys (see also below). In order to qualify the structural materials of a DEMO reactor a 14 MeV neutron source with relevant fluence will be required. The International Fusion Materials Irradiation Facility (IFMIF) is now part of the "Broader Approach" and will be most likely constructed in parallel to ITER, thus being available in time for the qualification of materials in line with the Fast Track approach. In the following sections the status of the development of the above technologies at FZK is briefly outlined.

2. The development of "high temperature superconducting coils" for DEMO

HTS materials like Bi-2223 tapes are nowadays available on the market for technical use [1]. However, the HTS materials are known to show a strong anisotropy. As a consequence the critical current is anisotropic as well as its dependence on the magnetic field and its orientation. As an example for the field anisotropy calculated from $H_{c2,//}$ over $H_{c2,\perp}$ (parallel and perpendicular to the superconducting CuO_2 planes of the HTS materials) a factor of 5–7 for YBCO, and 50–200 for Bi-2223 has been found [2]. To achieve high transport currents a strong texture in the HTS material is necessary. Grain boundaries cause additional problems for transport currents [3]. Therefore a high critical current is only achieved when neighboring grains have almost the same orientation i.e. only grain boundary angles as small as possible are present. These inherent properties demand for an almost perfect texture of the HTS materials.

These problems are solved for Bi-2223, which requires only a one-dimensional *c*-axis texture and industrial conductor lengths are already available in the km range (>2 km). This material has been used already for high current applications e.g. the 68 kA current lead demonstrator for ITER which was successfully tested with He and LN_2 cooling [4]. However, while the 68 kA current lead demonstrator works fine at 70 K when the HTS material is exposed only to its self produced field, the same conductor (Bi-2223) in a typical Tokamak TF coil field of 13 T would have to be operated at a temperature of approximately 20 K in order to have a high enough irreversibility field $H_{irr}(T)$.

For a technical use at high field and higher temperatures YBCO coated conductors are most promising. Incline substrate deposition (ISD) [5] or ion beam assisted deposition (IBAD) [6] are methods to grow textured buffer layers on metal tapes serving as the necessary substrate for the epitaxial growth of the textured YBCO films. Vacuum deposition techniques for YBCO, as pulsed laser deposition (PLD), actually provide the best film qualities. The record conductor performance is 245 A/cm-width over a 212 m tape lengths [7]. Another much more economic approach is the use of rolling assisted biaxially textured substrates (RABiTS), in general made from Ni, NiW or other Ni-alloys [8]. In this case the cube texture of the RABiTS substrate tape is adopted through the epitaxial deposition of buffer and YBCO layer.

All these techniques can produce YBCO coated conductors with very high quality but there are several general problems.

(1) At least one buffer layer between substrate and YBCO is necessary to prevent chemical reactions of the tape material and the YBCO layer which are commonly insulating oxides.
(2) The deposition process is slow for vacuum deposition techniques, being typically 1–3 m/h, which is cost intensive.
(3) The growth and the necessary annealing of YBCO needs a well defined oxygen atmosphere which complicates the processing.