

HIGH HEAT FLUX MATERIALS: STATUS AND PERSPECTIVES

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Present design concepts for future fusion reactors include high heat flux components (HHFC) which have to be operated at extreme physical conditions. Even though the exact in-service conditions are unknown today, it is clear that heat, neutron, and particle fluxes will exceed those of experimental near-term concepts like ITER. A comprising and sufficient knowledge of all plasma-surface interactions and their implications is presently not available. Also the extent of possible control instruments or prediction capabilities for off-normal plasma events like disruptions and the appearance of localized modes is not known yet. Even based on non-conservative estimations and extrapolations of possible operation conditions, material selection in the designs for HHFC is a very complex problem.

To make a continuous operation possible, the plasma has to be cleaned from helium and unavoidable contaminants from the first wall. These ions are redirected from the burning plasma by magnetic fields towards cooled target plates of the divertor. During their impact, the high-energetic ions loose kinetic energy and recombine with electrons to neutral atoms which can then be removed by vacuum pumps. Due to the particle impact, the divertor is the component of a fusion power plant with the highest thermal loads. About 15 % of the total fusion power has to be removed by the divertor while peak loads of 10-20 MW/m² have to be considered. Moreover, like all plasma facing components divertors are also exposed to fast neutrons. As a consequence, damage, wear, transmutation, and aging can reduce the durability of some divertor components significantly. Therefore, divertors have to be designed modular for an easy exchange of these parts. That is why current R&D programmes focus on the development of high-performance materials as well as on design studies of divertor modules.

The in-service temperature of the involved parts is a major design criterion and depends strongly on the underlying cooling concept (water, gas, or liquid metal). Thermal conductivity, creep, and recrystallization, are typical properties which restrict the design significantly on the upper temperature limit while brittleness, irradiation damage, or tritium retention considerations narrow the materials of question to the low-temperature range. Moreover, specific defect processes such as helium bubbles, swelling, surface reactions, or crack formation have to be considered for the use of plasma-facing materials and for the application of possible coatings and protection layers.

There are divertor design studies on different characteristic length scales which demonstrate the importance of efficiency, on the one hand, but also show the difficulties connected with fabrication issues on the other. Processability, joining, and compatibility are just a few key words related to component production and assembly. Finally, there are natural criteria like the availability of resources and there are environmental criteria like low-activation which rule out a significant number of possible elements.

This paper discusses the current status of HHFC materials and outlines development-oriented targets for possible applications in future fusion reactors. The complex interrelations of design goals, material properties, and operation conditions will be described and structured. Current research results are used to illustrate this multifaceted topic.