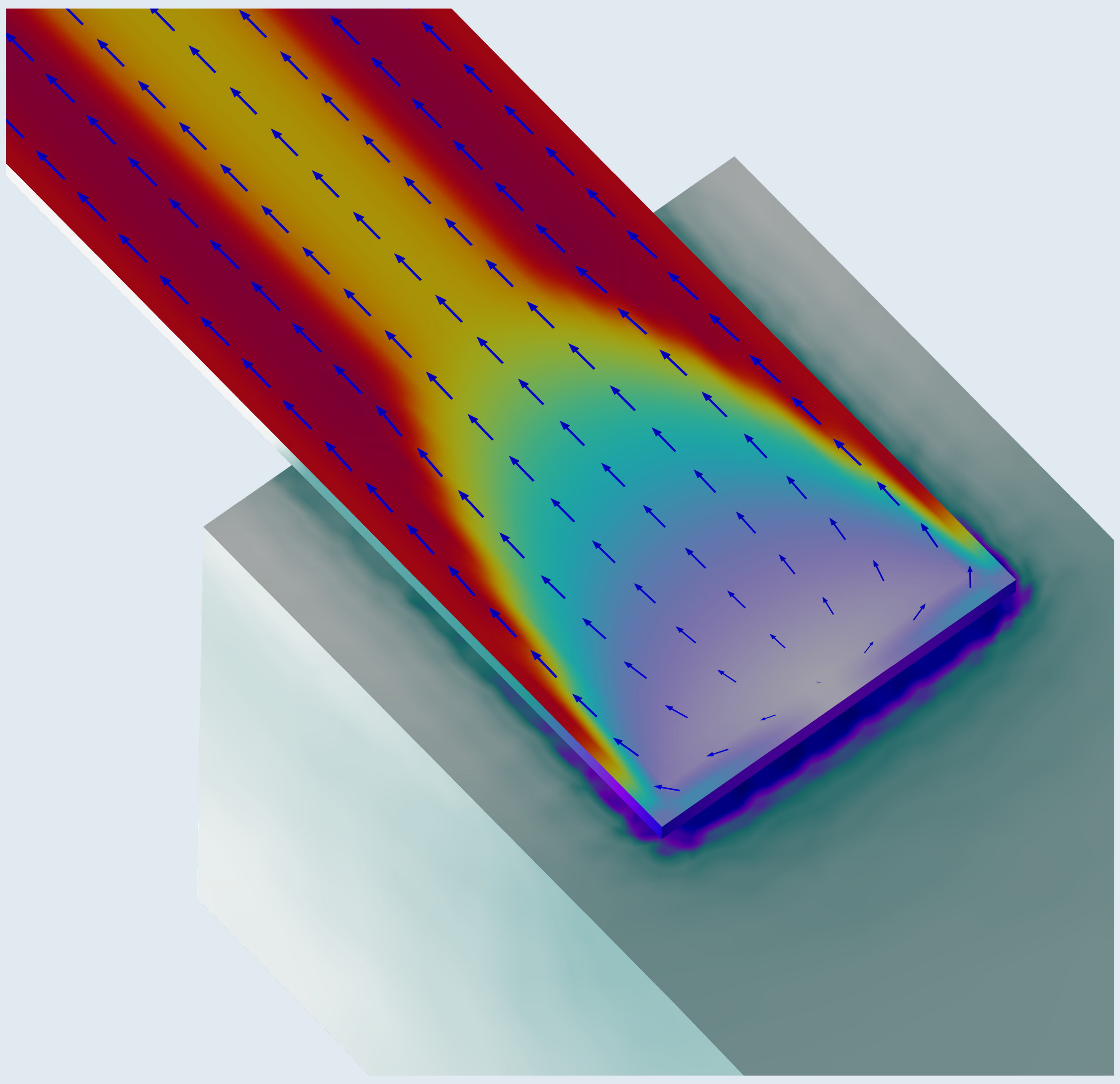

Modeling of High-Temperature Superconductors

High-temperature superconductors (HTS) behave according to challenging physics. Improved modeling capabilities can help with the introduction of HTS technology to new applications.

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Abstract

Having a large conductivity implies a small skin depth. Perfect conductors would have a skin depth of 0, with currents only flowing on the surface. This also applies to HTS materials, where currents are concentrated near the surface even in de DC limit. These surface currents will locally reach the critical current density, which means that the HTS suddenly becomes locally resistive. This resistance can cause substantial heating.

As HTS only function at cryogenic temperatures, such heating must be understood. Modelling of HTS materials is complicated by the highly nonlinear behaviour near the critical current density. Moreover, the nonlinearity causes hysteresis effects such that studies must be performed in time-domain. Still, improvement in modelling allows effective simulation of HTS materials.

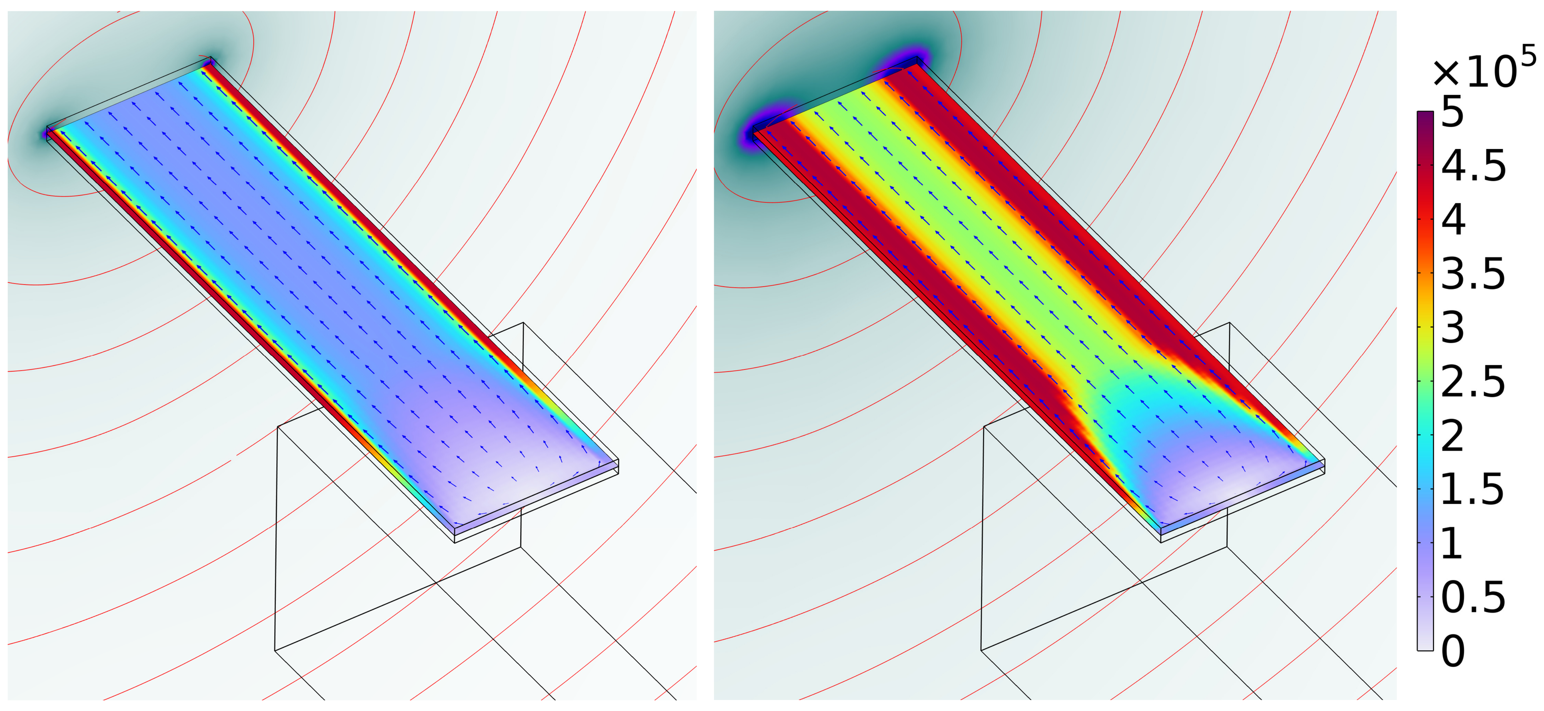

FIGURE 1. Current density (A/m) through an individual HTS tape, and cut plane showing the magnetic field. Current is coupled into the tape from a copper block (transparent). Left figure is at 3500 A, right figure is at 7000 A.

Methodology

HTS material is typically produced as a thin layer deposited on a substrate. This comes in the form of long tapes. We use a weak form boundary interface to describe the currents in the thin HTS layer, coupling this to electromagnetic fields allows the behavior of the HTS to be studied. Simulations are performed in time domain, including the ramping of the current flowing through the superconductor.

HTS applications typically use stacks of many such tapes, which require custom models to reach reasonable performance. Symmetry and homogenization of the tape stack are useful strategies for improving model performance, though care should be taken that such an approximation is valid for the application at hand.

Results

We are able to simulate currents through HTS material, giving the current distributions and the associated magnetic field. Furthermore, we can calculate the electric losses in both the superconductor and normal conductor.

Components containing a limited amount of HTS tape can be modeled in full fidelity, including the individual HTS tapes. Larger systems can also be simulated if approximations sufficiently reduce the problem. For example, this enables calculating the behavior and electric losses in the various HTS coils of a tokamak reactor (figure 2).

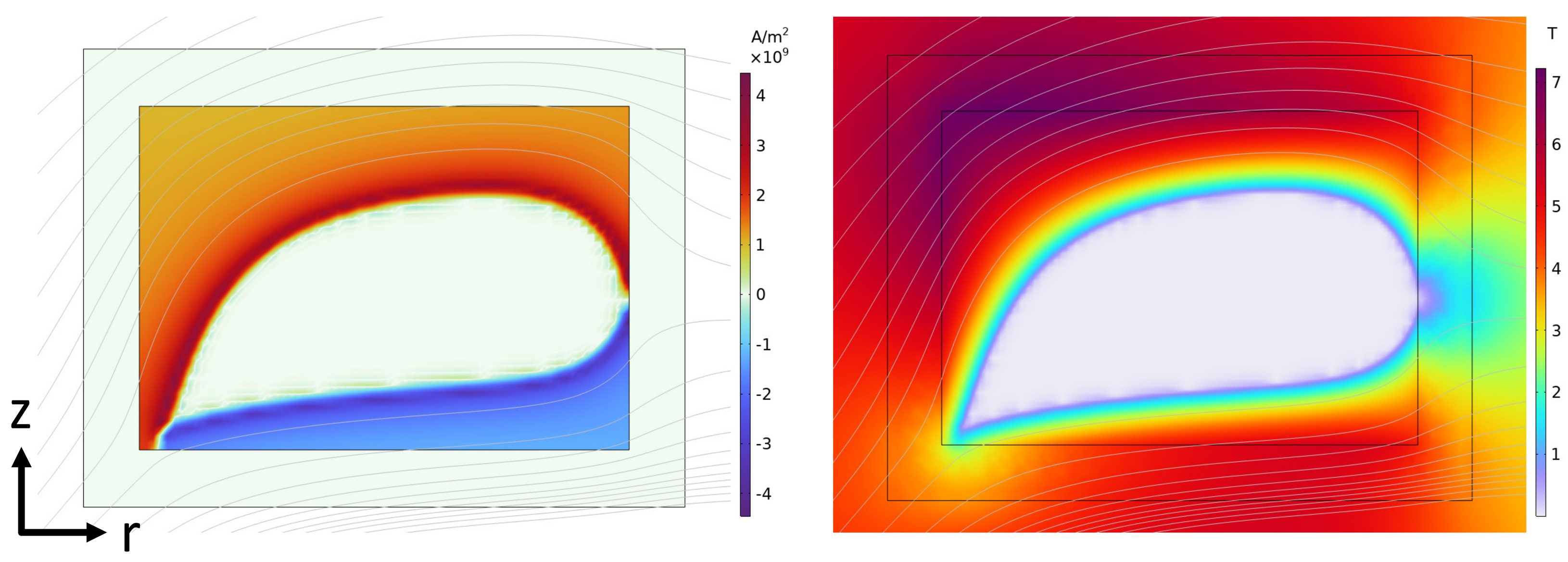

FIGURE 2. Current density and flux density in a turn of the central solenoid coil of a tokamak fusion reactor. The turn consists of >100 HTS tapes stacked radially. The turn is approximated using homogenization. Notice that the current distribution counters the penetration of the magnetic field.

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