NUMERICAL SIMULATIONS OF SUPERCONDUCTOR STABILITY AGAINST QUENCH

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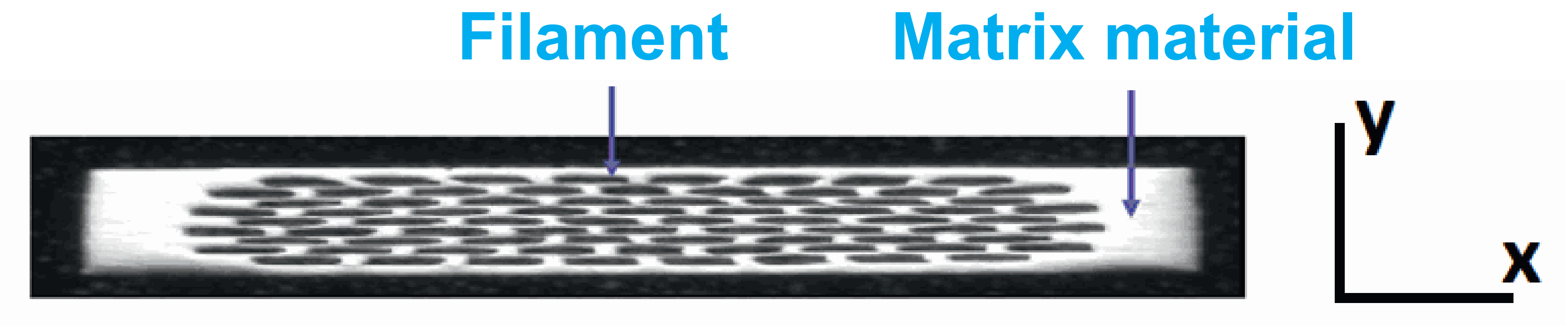
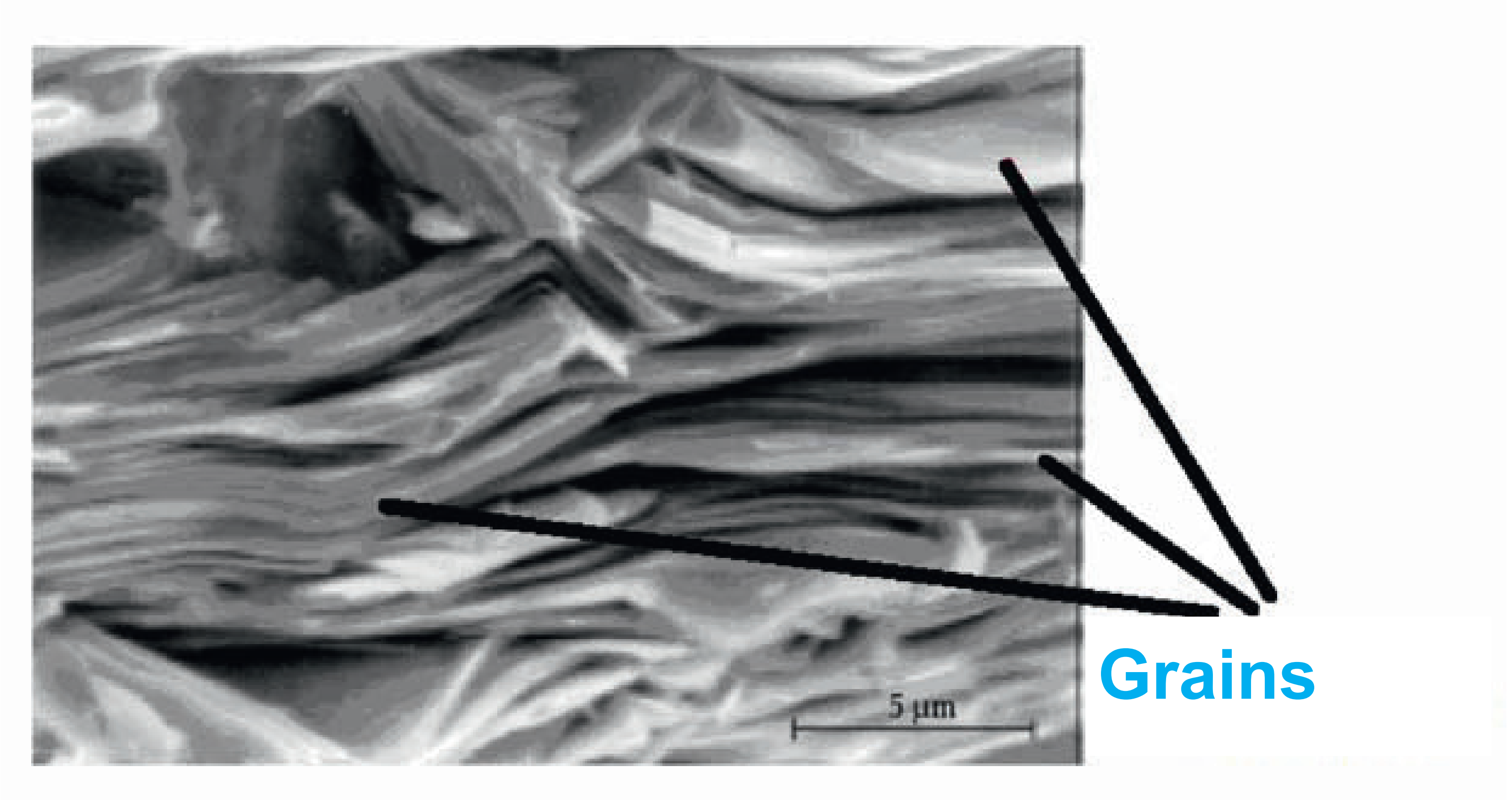
A superconductor is stable if it does not quench, which means if it under a disturbance does not perform a most undesirable, sudden phase transition from its superconducting to normal conducting state. Quench proceeds on very small timescales (ms and below) and may lead to local damage or even to destruction of the superconductor. Contrary to standard stability models, the present paper considers the impact of local position and intensity of disturbances on superconductor stability (local flux flow and Ohmic resistance losses).



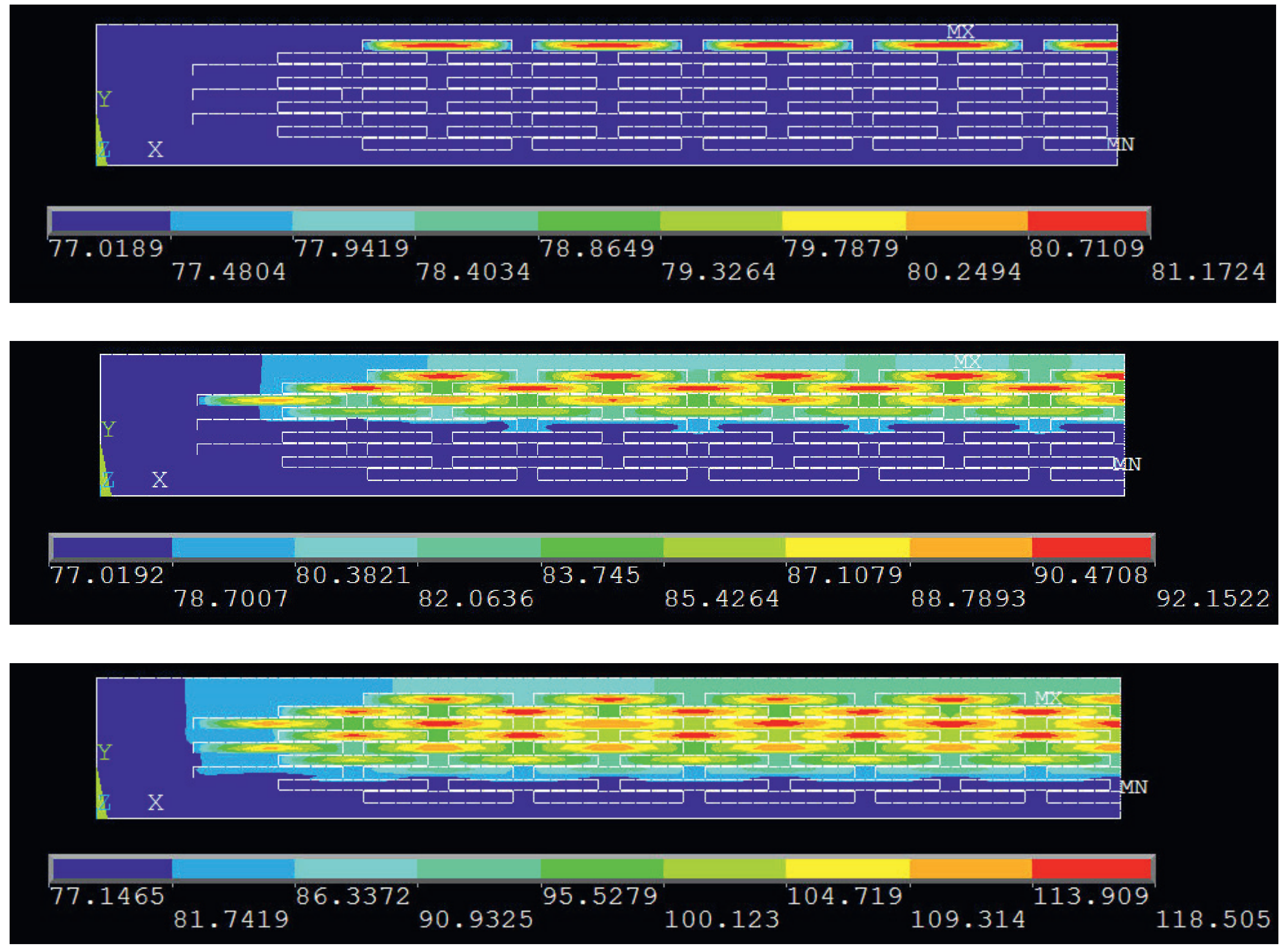
A) Cross section of the BSCCO 2223/Ag tape of the Long Island Cable superconductor (Source: Nexans). One tape contains 91 identical filaments each composed of fine superconductor grains; filaments and grains are embedded in a Ag-matrix material. The tapes are switched in parallel to yield the total, multi-filamentary superconductor cable cross section. Dimensions: x ≤ 280 μm (filament) and about 3.8 mm (total tape width), and y ≤ 30 μm (filament) and y = 250 to 300 μm (total tape thickness). Critical temperature of BSCCO 2223 is 108 K, at zero magnetic field.



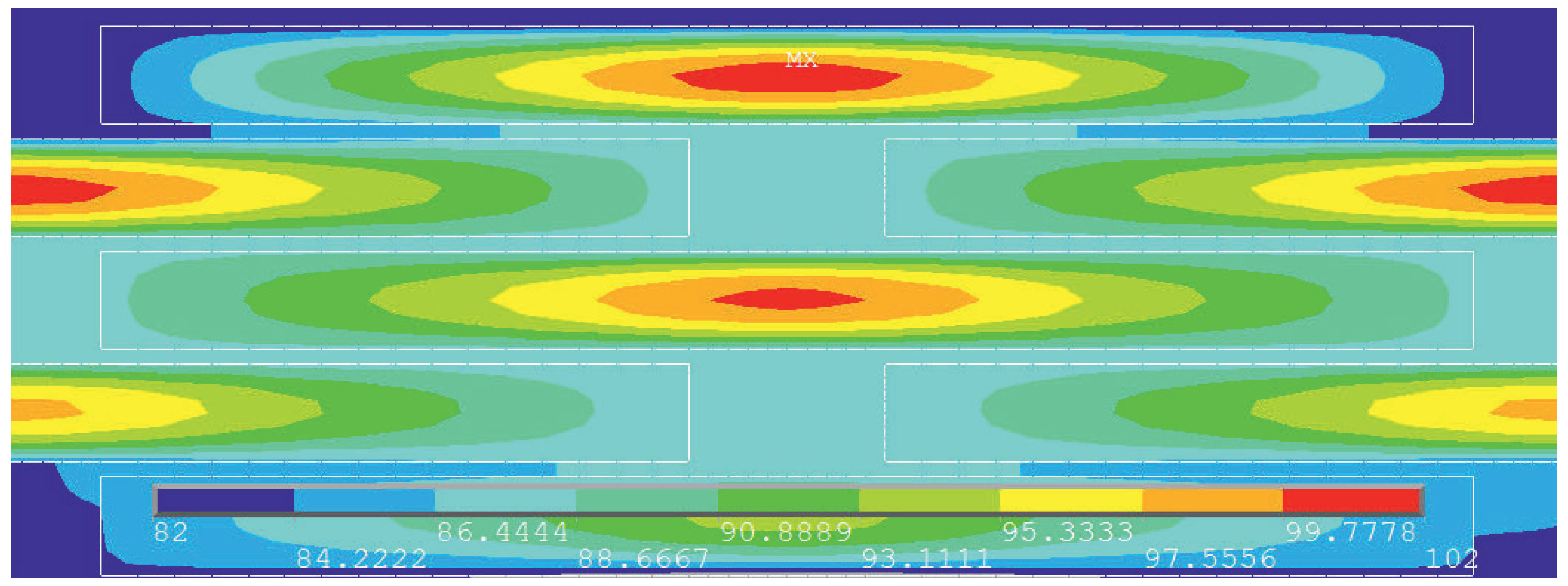
B) Superconductor thin, plate-like grains in the filaments. Orientation of the grains results from a Powder in Tube manufacturing process.

Problem:
How to numerically model the hierarchy of grains, tapes and superconductor cable?

- Very detailed conductor geometry
- Strongly different materials transport properties (electrical, thermal), with very large anisotropy in the grains
- Radiation heat transfer within the grains
- Complicated mesh (thin film dimensions)
- Convergence of the Finite Element calculation scheme



C) Numerical (Finite Element) simulation of transient temperature fields, T(x,y,t), in a single multi-filamentary, superconductor tape, at t = 7.6, 8.1 and 8.6 ms (from top to bottom). The disturbance starting at t = 6.5 ms results from a sudden increase of transport current to a fault (20 times increase over nominal transport current, within 2.5 ms). Losses initially arise from flux flow resistance (transport current density exceeding critical current density), later (bottom diagram) followed by Ohmic resistance losses. Calculations apply $\lambda_{Total} = \lambda_{Cond} + \lambda_{Rad}$, with radiative conductivity, λ_{Rad}, using wave length dependent extinction properties obtained from application of rigorous scattering theory. The Meissner effect is simulated in each of the up to 30 k Finite Elements. Only the left half of the total tape width is shown.



D) Transient temperature distribution (detail) within filaments, Ag-matrix and tape under a strong disturbance. Local temperatures are identified from the horizontal bar at the bottom of this figure (temperature steps of 2 K). In this Figure, the losses arise from flux flow resistance (later, when locally T > 108 K, followed by Ohmic resistances). Thin white lines indicate overall filament contours. The Figure clearly shows that superconductor temperature, within the filaments, is NOT homogeneous. The symbol MX identifies the position where maximum conductor temperature is expected.

Results and Conclusions

- It is not realistic, even in thin films, to assume uniform conductor temperature: Even an extended fault transport current density exceeding critical current density), and corresponding initial flux flow losses, would disturb an otherwise homogenous temperature distribution
- Resistive states and current limitation, as they depend on local temperature, cannot be homogeneous, but flux flow resistive and Ohmic resistive states will coexist, side by side, not permanently, in the conductor cross section
- Critical current density, critical magnetic field and transport current distributions thus cannot be uniform
- Transport current transiently oscillates through the conductor cross section, since temperature field is transient
- Non-convergence of the numerical scheme could help to identify local positions and time of occurrence of a quench