

# Ternary molybdenum chalcogenide superconducting wires for ultra-high field applications

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**Summary - Ternary Molybdenum Chalcogenide (TMC)** superconducting wires were developed and studied in industry and academia before high temperature superconductors were discovered (1986/87). Although TMC is a low temperature superconductor ( $T_c$  up to 15 K), upper critical fields in the 60 T range were measured (PbMo<sub>6</sub>S<sub>8</sub> = PMS). Regarding the generation of ultra-high magnetic fields, today TMC superconducting wires may be considered as an attractive alternative to High Temperature Superconductors (HTS). Their physical properties are nearly isotropic and they can be manufactured with round or rectangular cross section. No reaction heat treatment is required allowing to use the winding technology for NbTi magnets. The mechanical properties, i.e.  $R_{p0.2}$  (Fig. 3), are excellent. Finally, the purchase price \$/kg of a TMC superconducting wire, as well as the \$/kAm index, is almost one order of magnitude lower than HTS.

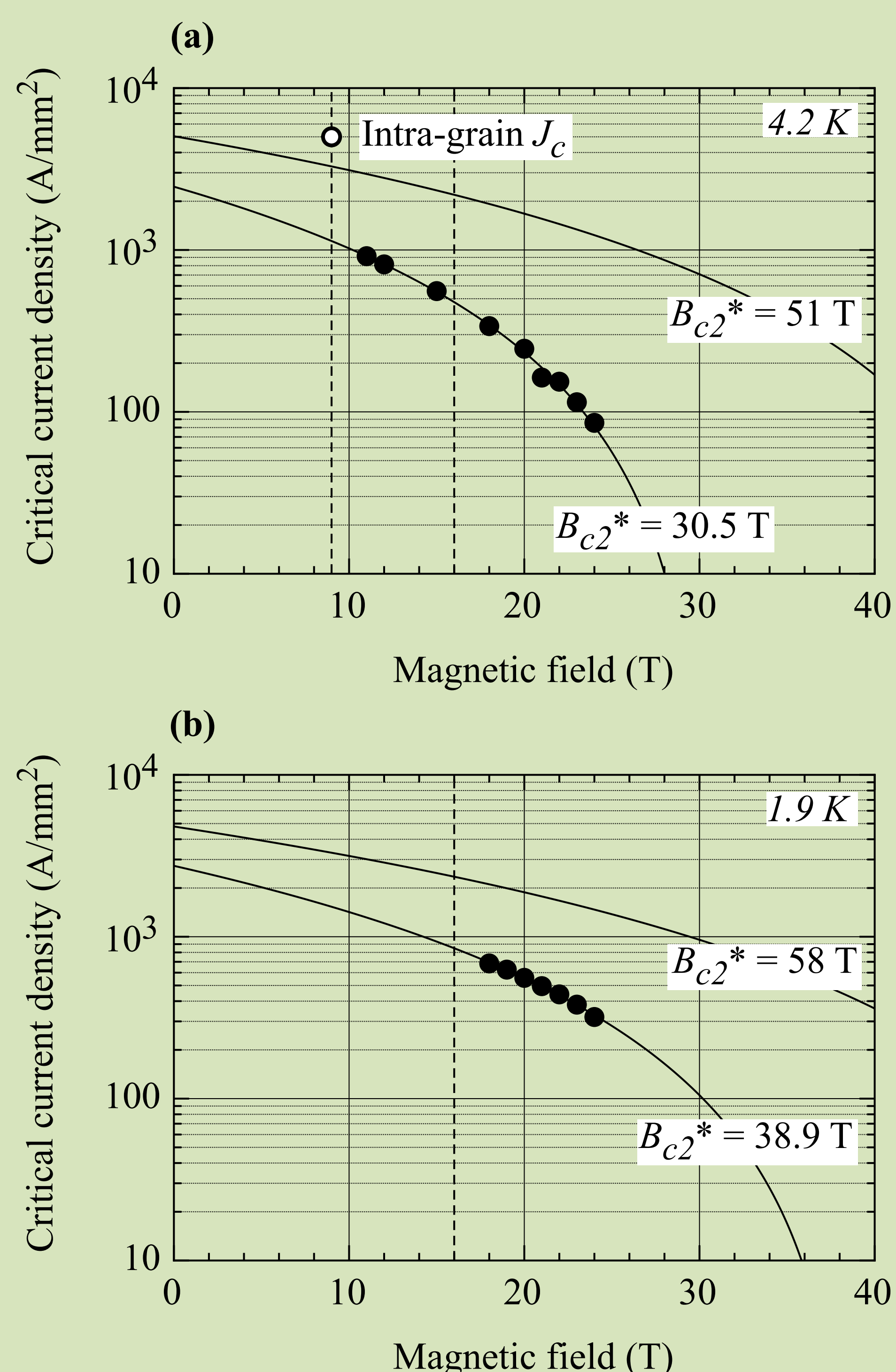


Fig. 1 – Critical current density vs. magnetic field for a monofilamentary TMC (PMS) wire (courtesy of N. Cheggour, JAP 1997). The  $B_{c2}^*$ , obtained by fitting to zero pinning force, is far from the optimum bulk value. The  $J_c$  with optimized  $B_{c2}^*$  was calculated by a scaling law.

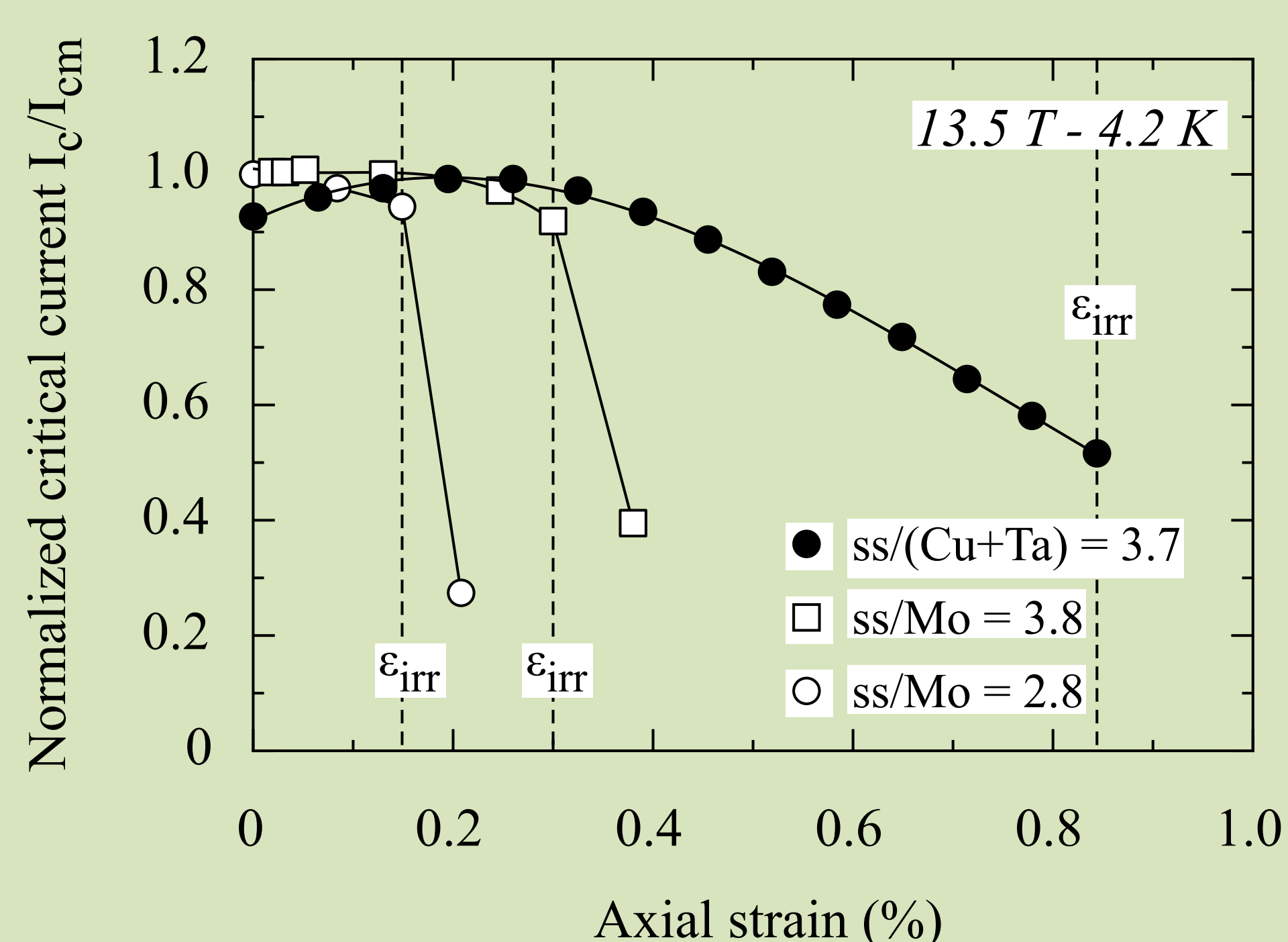


Fig. 2 – Normalized critical current vs. axial strain for PIT monofilamentary TMC (PMS) wires (courtesy of Goldacker et al., *Cryogenics*, 1989 and B. Seeber et al. TAS, 1991). Note that the irreversibility limit increases with higher stainless steel content. Wires with ss/Mo matrix are not optimized concerning the ss/Mo fraction.

Table I. Prospective critical current densities (non-Cu value) of an optimized TMC (PMS) superconducting wire calculated with a scaling law ( $B_{c2}^* = 51$  T and 58 T at 4.2 K and 1.9 K, respectively).

$J_c$ (A/mm <sup>2</sup> )	4.2 K	1.9 K
10 T	3110	3155
16 T	2190	2350
20 T	1675	1880
25 T	1135	1375

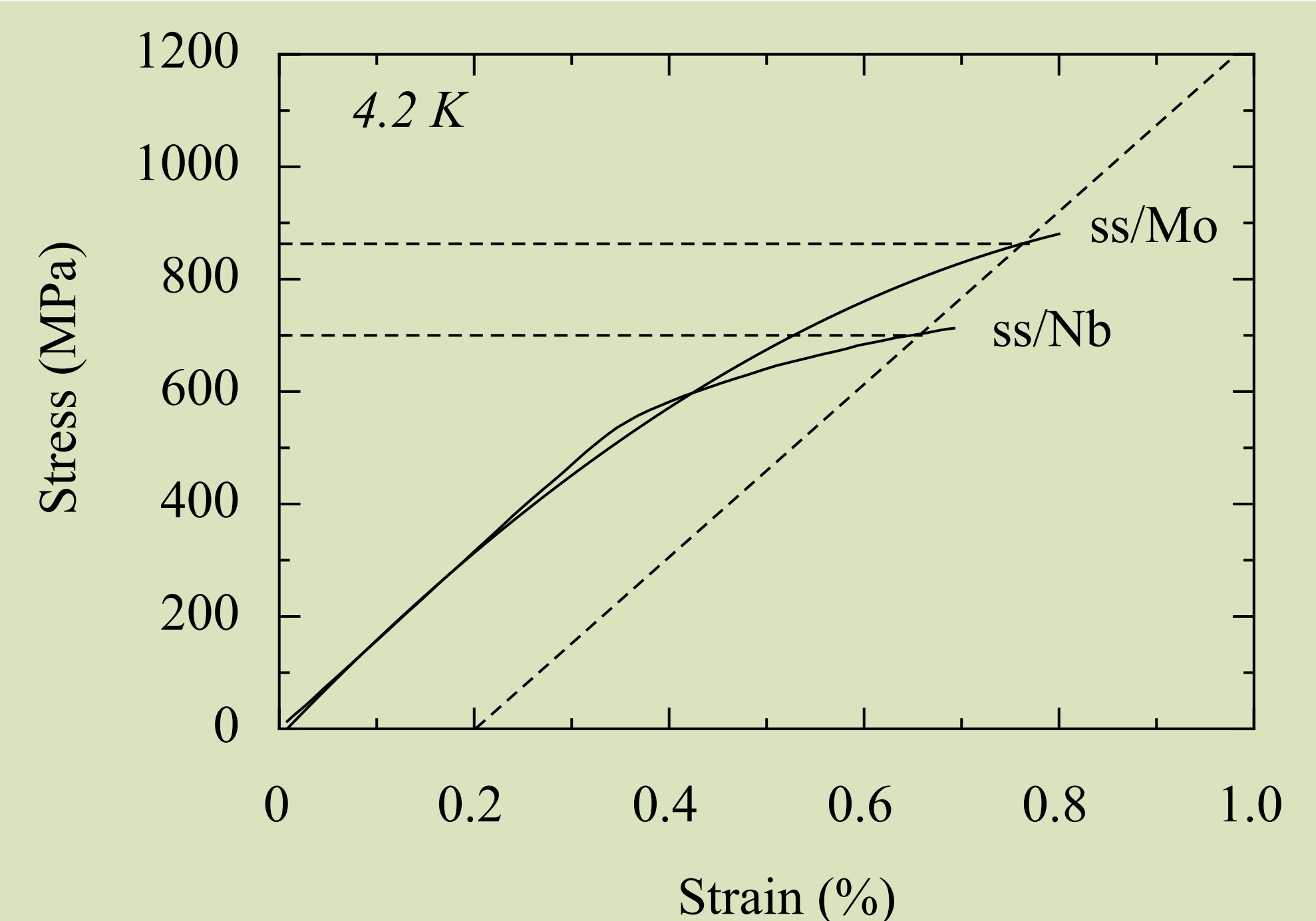


Fig. 3 – Stress vs. strain of monofilamentary TMC (PMS) wires with 30.5% TMC, 18.3% Mo and 51.2% stainless steel (ss/Mo) (courtesy of B. Seeber, *Handbook of Applied Superconductivity*, IOP, 1998) and a wire with 6% TMC, 9% Nb, 15% Cu and 70% stainless steel (ss/Nb) (courtesy of G. Rimikis, Ph.D. dissertation, Karlsruhe, 1990). Note the high yield strength,  $R_{p0.2}$ , between 700 MPa and 860 MPa.

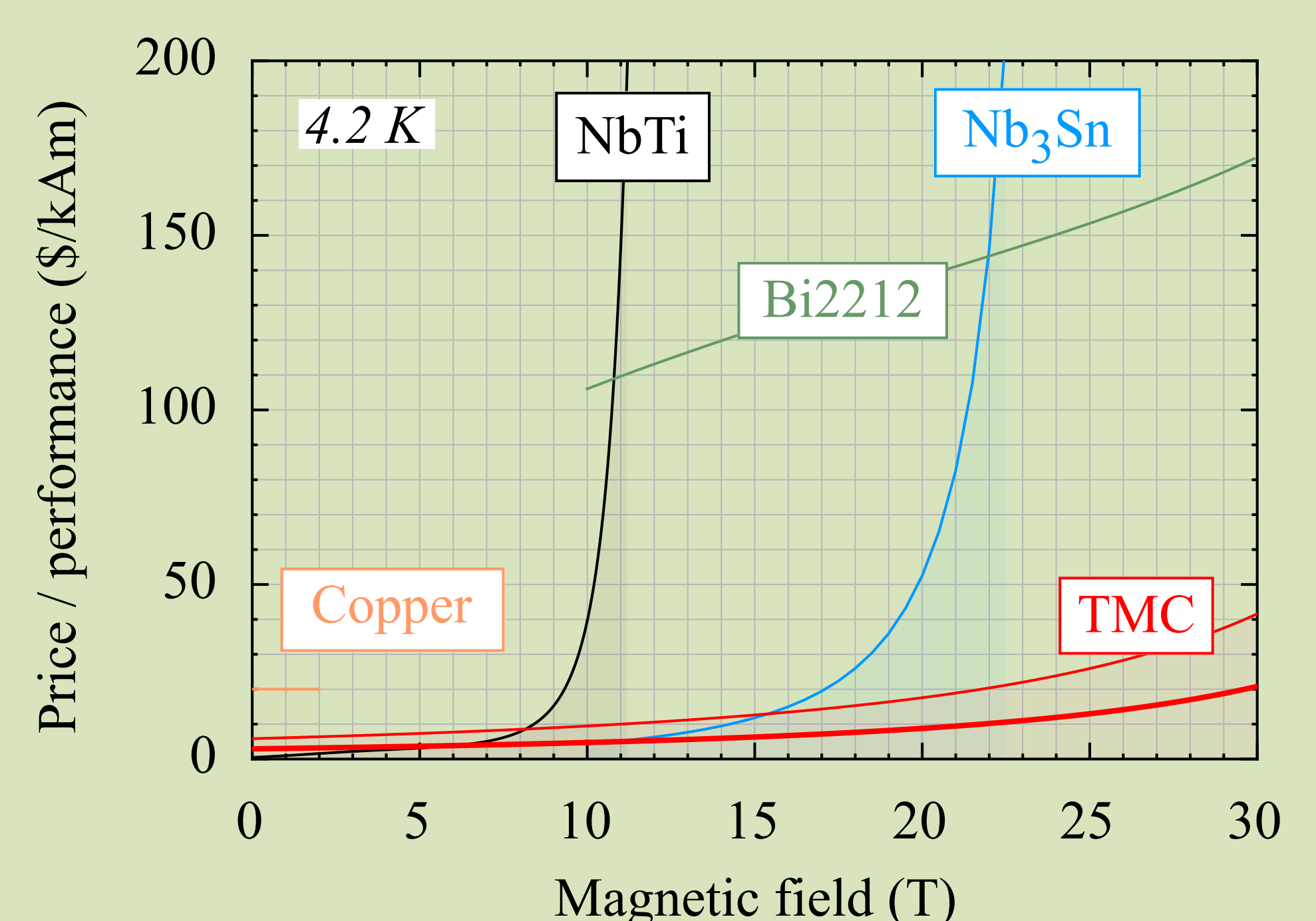


Fig. 4 – Price/performance (\$/kAm) vs. magnetic field for a TMC multifilamentary wire and comparison to copper, NbTi, Nb<sub>3</sub>Sn and Bi2212. Note that the \$/kAm index is proportional to  $(\$/kg)/J_{ceng}$ , where \$/kg is the purchase price of the superconducting wire. Supposing optimized  $B_{c2}^*$ , the upper line for TMC is with 920 \$/kg (stabilizer/superconductor = 1). The lower line is with 460 \$/kg (large scale production). NbTi: 195 \$/kg - R = 1.8, Nb<sub>3</sub>Sn (RRP-217 stack): 940 \$/kg - R = 1, and Bi2212: 10'360 \$/kg - R ~ 3.