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Critical current versus strain of long HTS and LTS technical superconductors up to 1000 A and 17 T

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CONTENTS

- Superconductors in magnets
- Nb_3Sn mechanical properties
- Survey of devices for measuring $I_c(\varepsilon)$
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- Results - *Nb_3Sn, MgB_2, Bi2223*
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High field solenoids and accelerator magnets are the main application for LTS and HTS

In both devices hoop stresses can reach very high values

A better knowledge of $\underline{I_c}$ as a function of <u>strain</u> and <u>stress</u> helps:

- to better exploit the potentiality of the conductors
- to compare different wires

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The Nb_3Sn case

Why developing Nb_3Sn wire for high field NMR magnets?

- NMR is one of the superconductivity largest customers (applications in chemistry, biology, pharmacology)
- Increasing demand for high field NMR magnets: higher field means higher resolution (more information)

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The goal is to reach the ultimate limit for Nb_3Sn

better material properties

better knowledge of the mechanical behaviour

special requirement for NMR: <u>persistent mode operation</u>

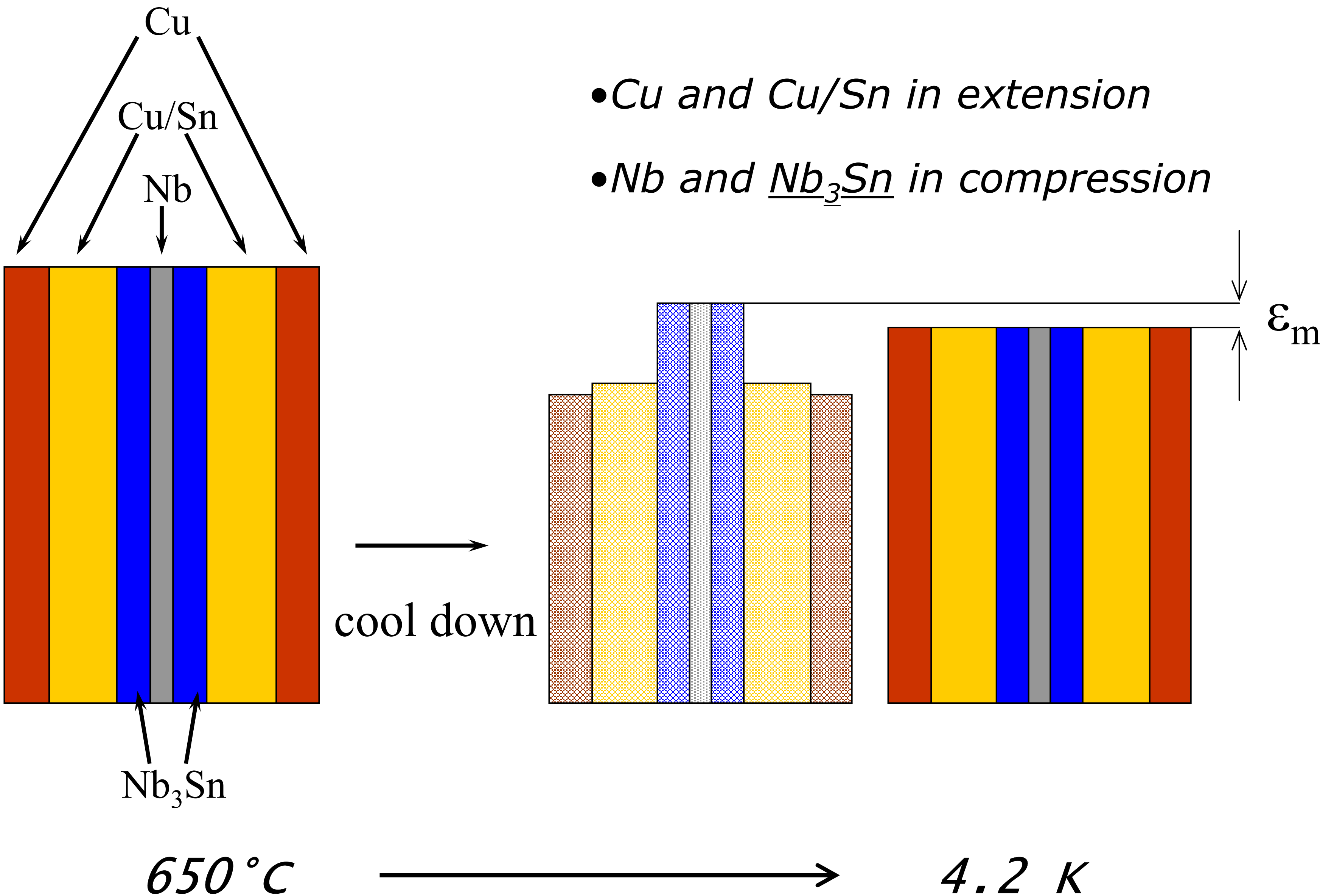
It is important to know

- *n value*
- *I_c at 0.1 μV/cm and below*

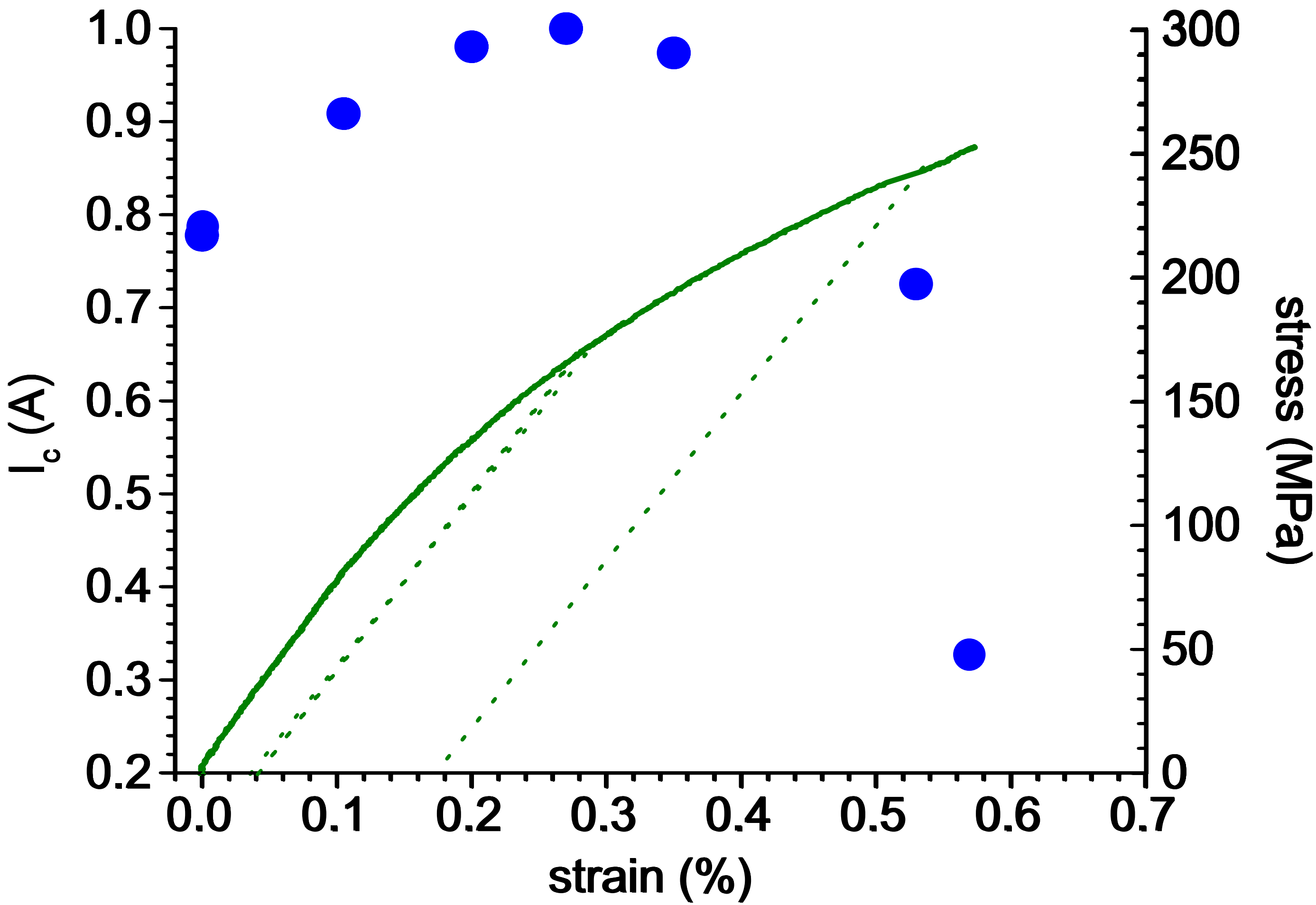
This holds also for other materials (Nb_3Al, Bi2223, Bi2212, MgB_2)

High quality (i.e. low electric field) measurements could be a tool to study the behaviour of superconductors under strain(crack formation and irreversible critical current)

- *Cu and Cu/Sn in extension*
- *Nb and <u>Nb_3Sn</u> in compression*



Overview of the behaviour of Ic vs strain vs stress in Nb_3Sn



Devices to measure $I_c(\varepsilon)$

- Prof. Katagiri - Fac. of Eng., Iwate Univ., Japan

- J.Ekin - NIMS, Boulder (CO), USA

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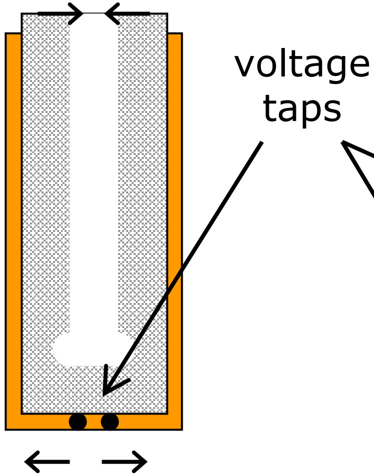
Devices to measure $I_c(\varepsilon)$

U shape spring

University of Twente and Tsukuba (HFML)



Made with steel or Ti; wire soldered over the whole length

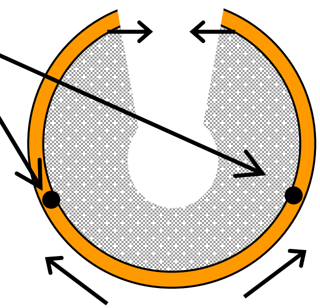
X •ε_m

X •current transfer

X •0.1 μV/cm

Pac-man

University of Twente



Made with Ti; wire soldered over the whole length

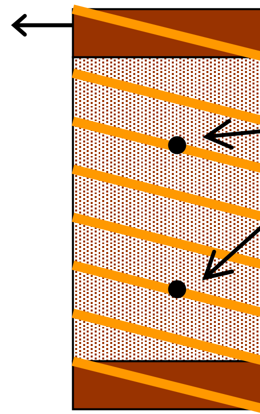
X •ε_m

V •current transfer

V •0.1 μV/cm

WASP

University of Durham



Made with Cu/Be; wire soldered over the whole length

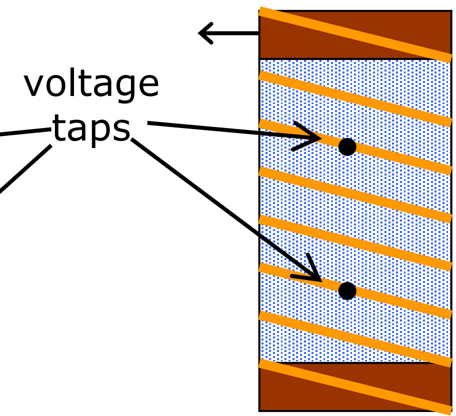
X •ε_m

V •current transfer

V •0.1 μV/cm and below

Geneva design

University of Geneva



Made with Ti; different mounting procedures

V •ε_m

V •current transfer

V •0.1 μV/cm and below

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High Field Laboratory at Geneva University

Sample holders

- Critical current on standard ITER barrel (3 samples per day 10T-17T)
- Critical current under strain (1.5 days per sample)
- Stress-strain (σ-ε)
- AC susceptibility (harmonics), resistivity
- RRR

Magnets

Split coil 6 T

Oxford 9 T

Oxford 17 T

(Bruker 21T)

temperature range

VTI: 4.2K/77K

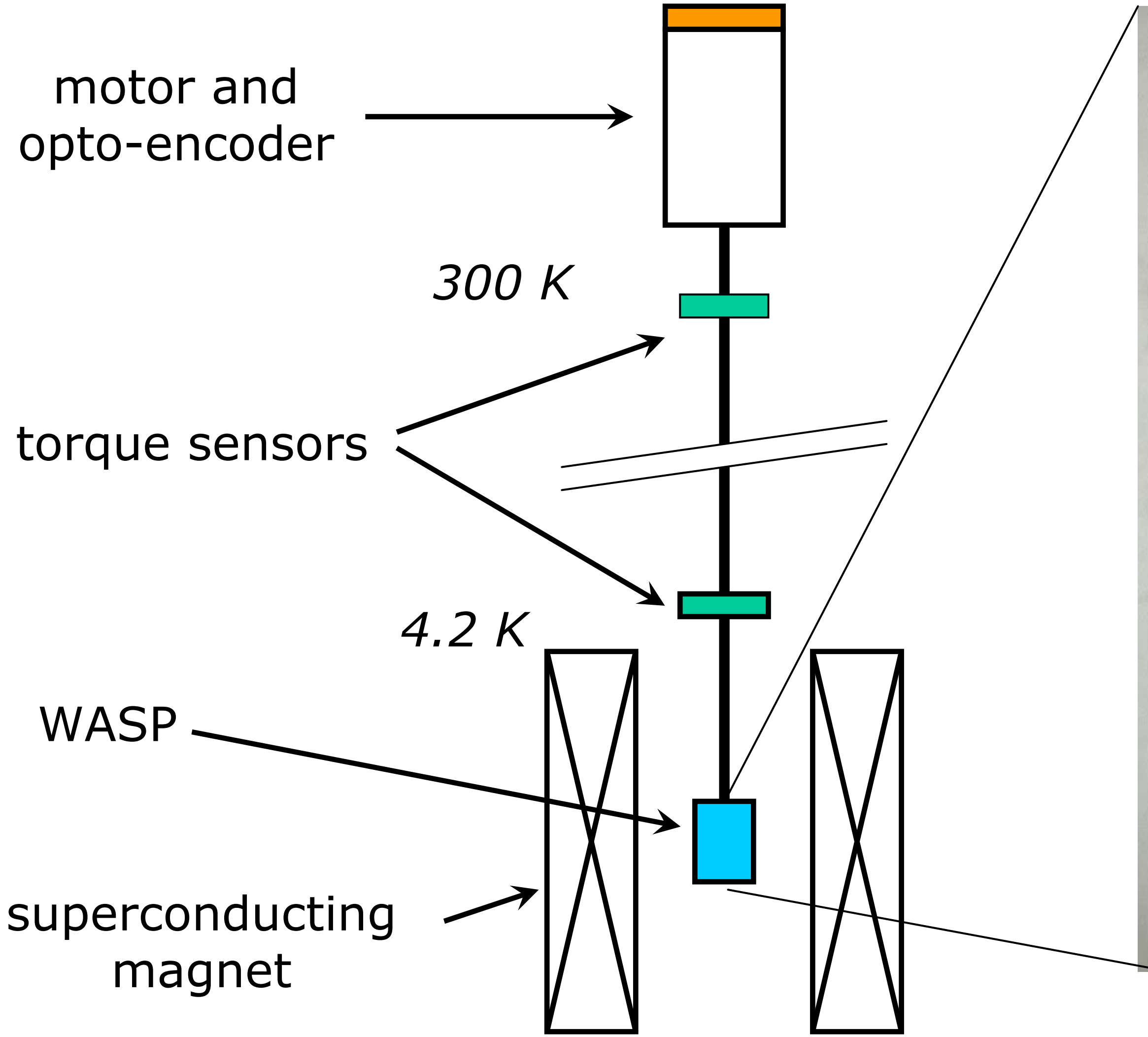
Modified Walters Spiral (WASP)

for $I_c(\varepsilon)$ measurements

specifications:

- **max current <u>1'000 *A*</u>**
- **wire length up to 0.8 meter**
- **max voltage taps distance 50 cm**
- **I_c criterion <u>0.01μV/cm</u>**
- **field up to 17 T (21 T soon)**
- **measurement of ε_m**

Geneva design



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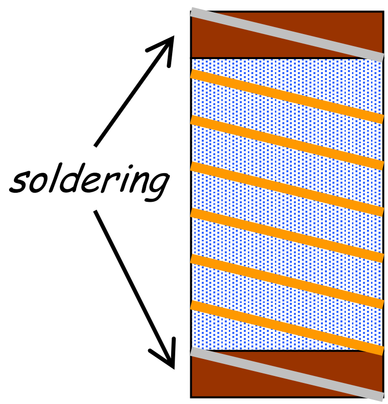
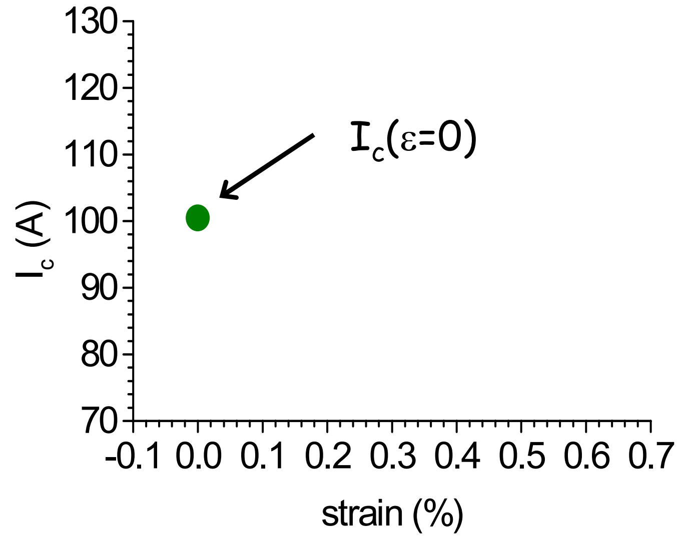
Mounting procedure

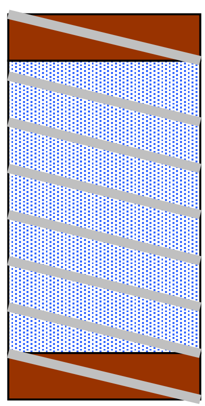
1^{st} cool-down:
the wire is mounted with some backlash and it is soldered only on the copper current leads

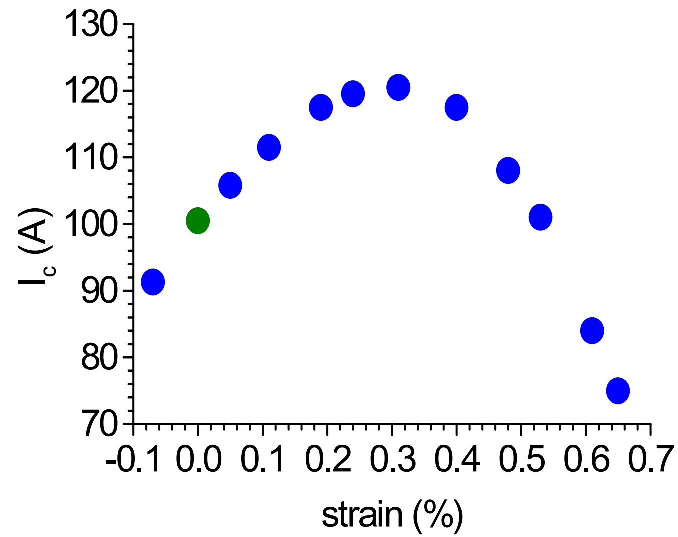


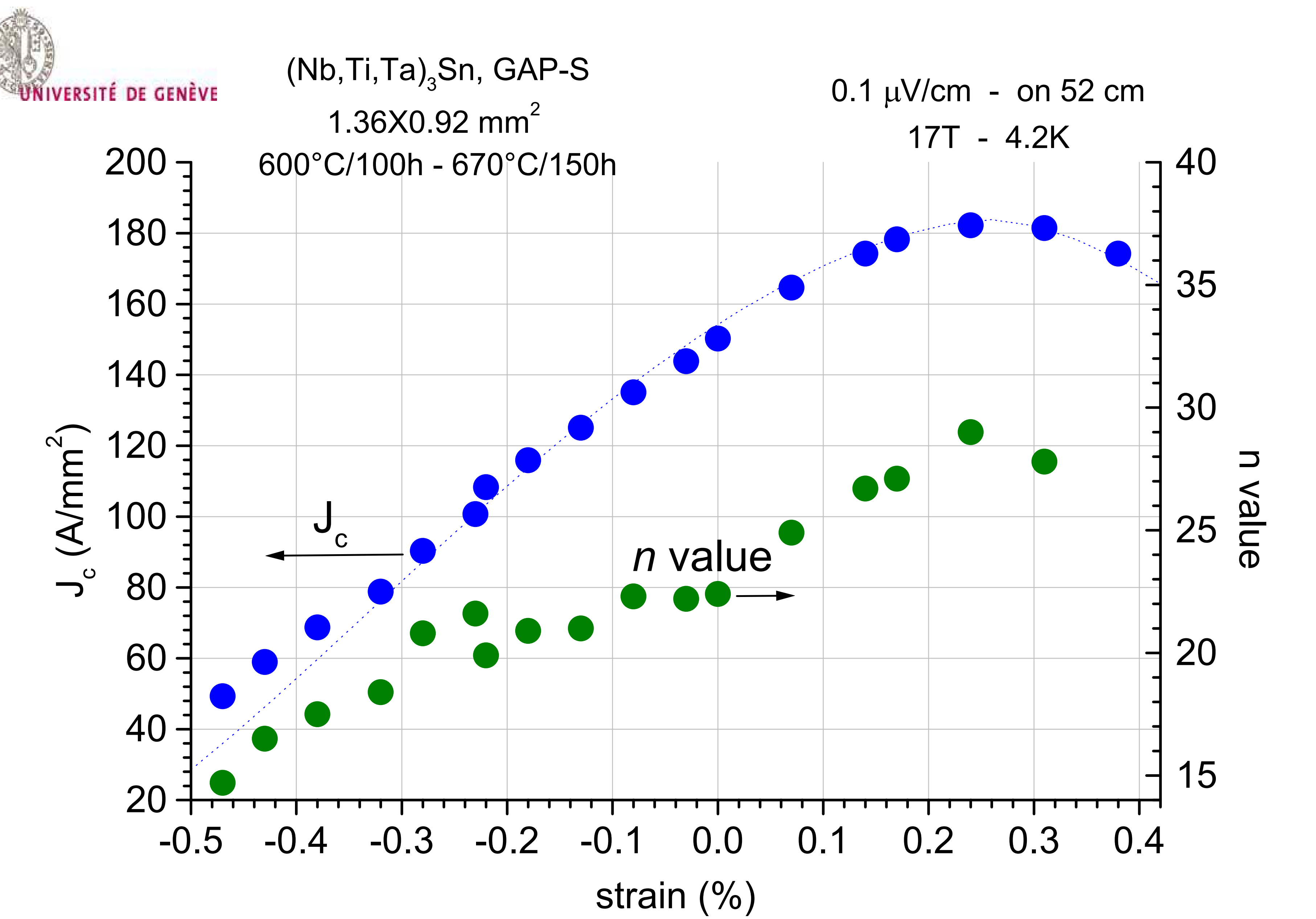


warm-up

2^{nd} cool-down:
the wire is soldered over the whole length.
The full I_c (ε) curve is acquired







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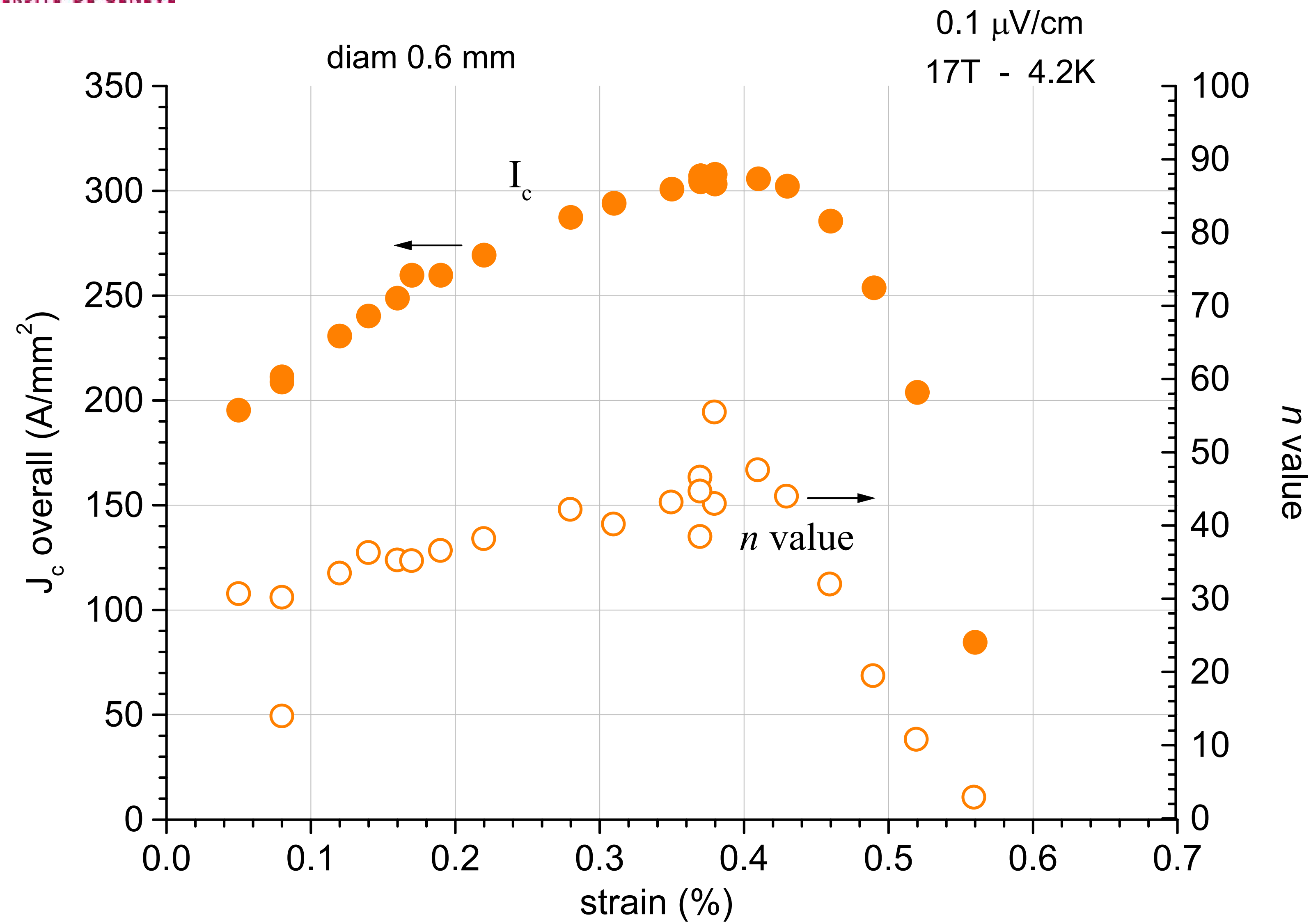
(Nb,Ti,Ta)3Sn, GAP-S
1.36X0.92 mm2
600°C/100h - 670°C/150h
0.1 μV/cm - on 52 cm
17T - 4.2K
Jc (A/mm2)
n value
Jc
n value
strain (%)
200
180
160
140
120
100
80
60
40
20
40
35
30
25
20
15
-0.5
-0.4
-0.3
-0.2
-0.1
0.0
0.1
0.2
0.3
0.4

SMI PIT wire



diam 0.6 mm
0.1 μV/cm
17T - 4.2K
I_c
n value
J_c overall (A/mm^2)
n value
strain (%)
350
300
250
200
150
100
50
0
100
90
80
70
60
50
40
30
20
10
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7

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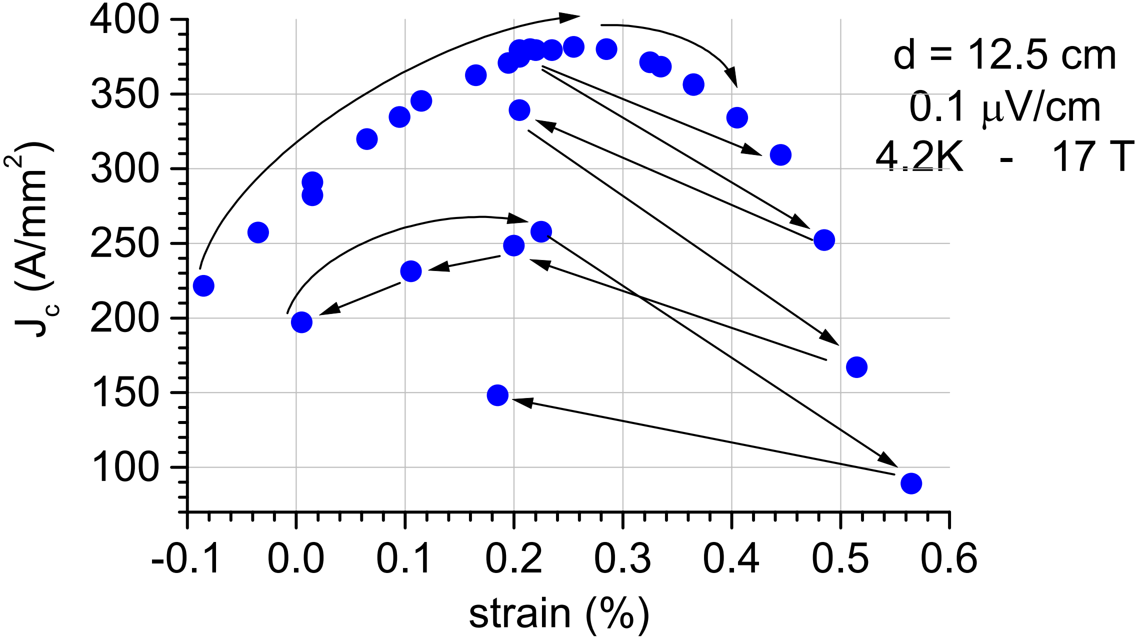
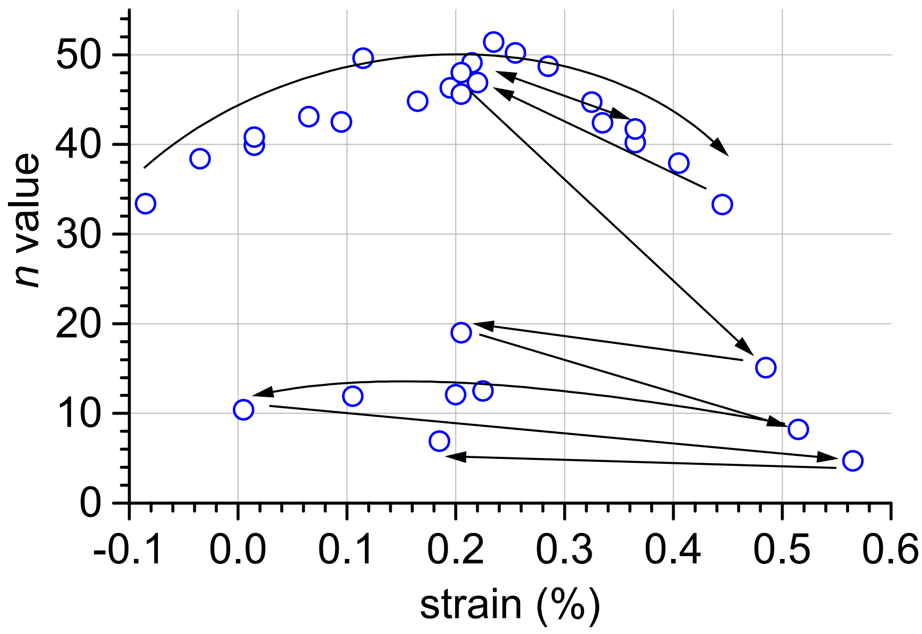
OST
HER wire 0.5mm diam
billet #7069

(2500A/mm² nonCu at 12T)





Crack formation and V-I curves

The idea comes from Prof. Osamura - University of Kyoto

They establish a correlation between the irreversible behaviour of I_c and the shape of the V-I curve.

What about Nb_3Sn?

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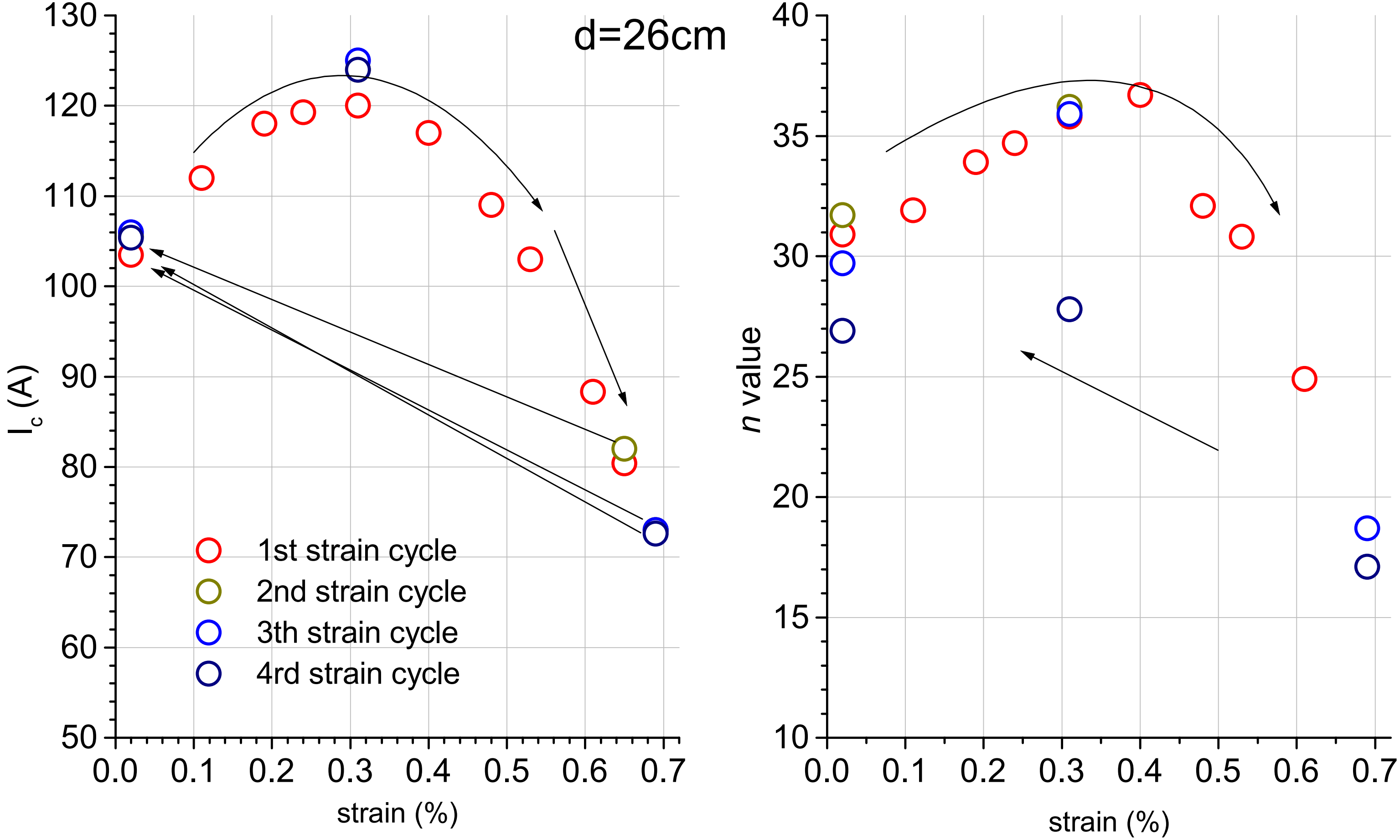
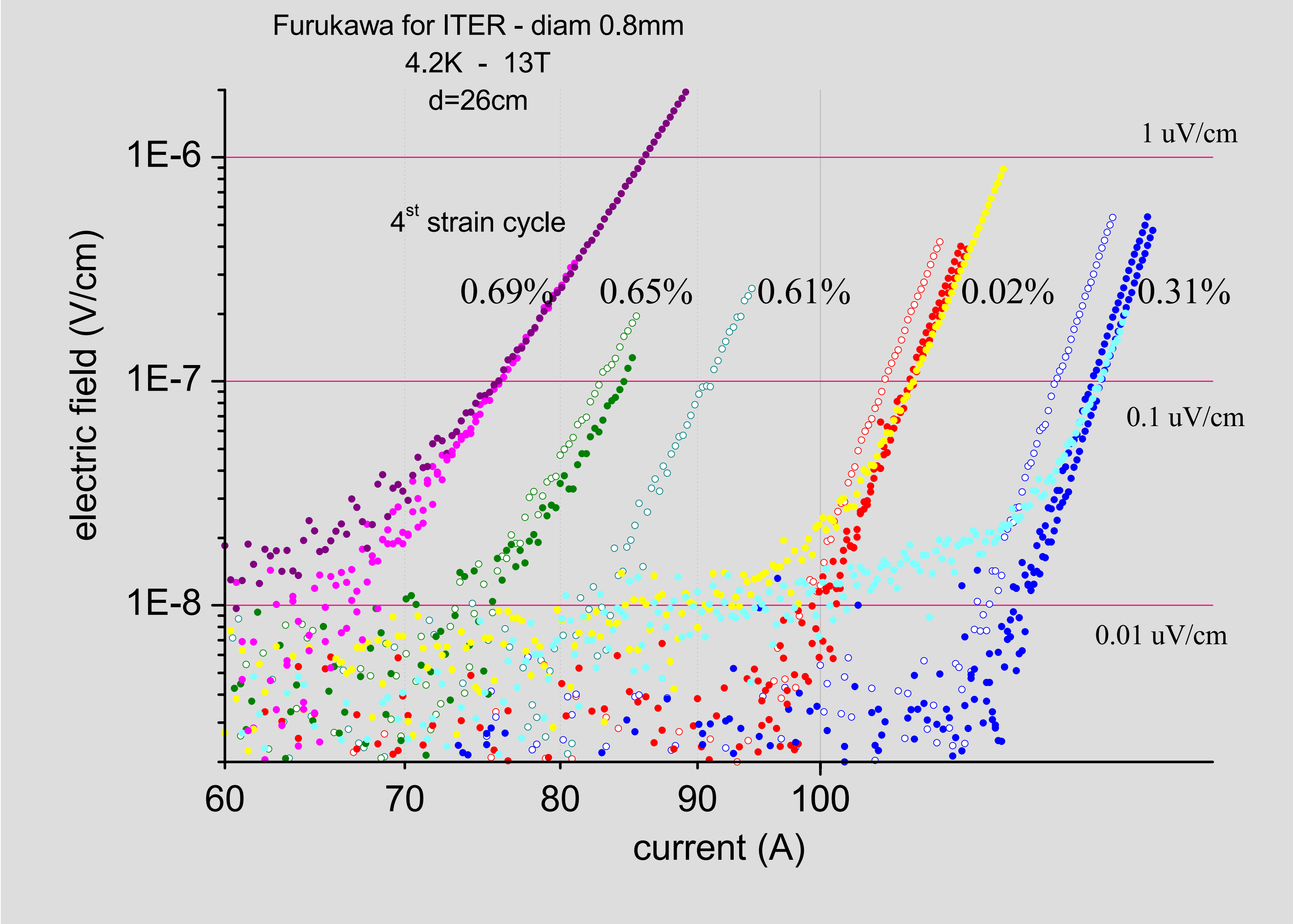
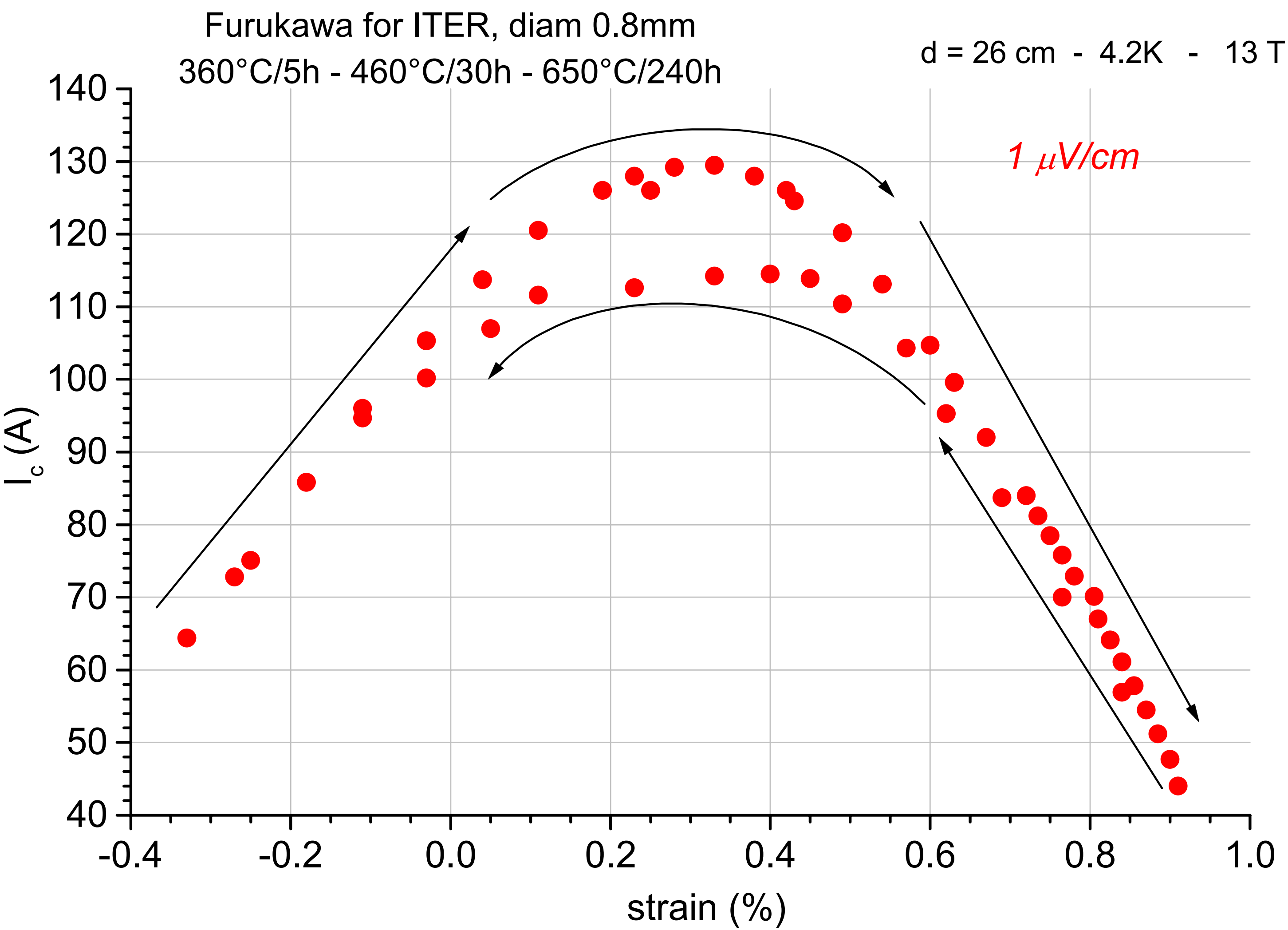
Furukawa for ITER - diam 0.8mm

4.2K - 13T

d=26cm




Furukawa for ITER - diam 0.8mm
4.2K - 13T
d=26cm
4st strain cycle
0.69%
0.65%
0.61%
0.02%
0.31%
1 uV/cm
0.1 uV/cm
0.01 uV/cm
1E-6
1E-7
1E-8
electric field (V/cm)
60
70
80
90
100
current (A)


Furukawa for ITER, diam 0.8mm
360°C/5h - 460°C/30h - 650°C/240h
d = 26 cm - 4.2K - 13 T
1 μV/cm
I_c (A)
strain (%)
140
130
120
110
100
90
80
70
60
50
40
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
1.0

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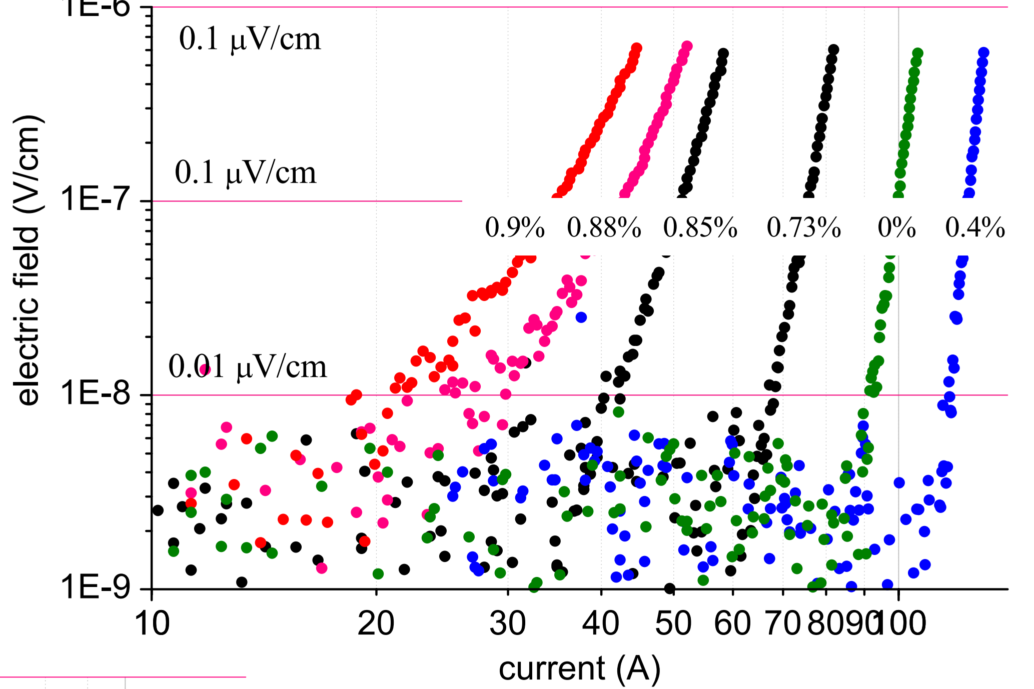
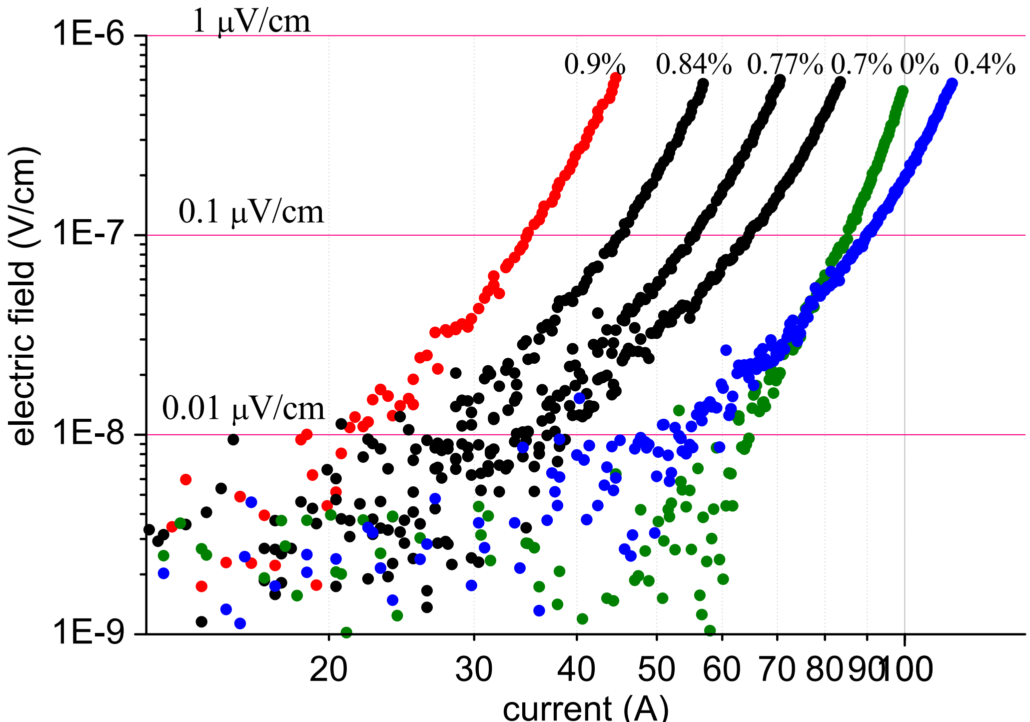
Loading





Unloading

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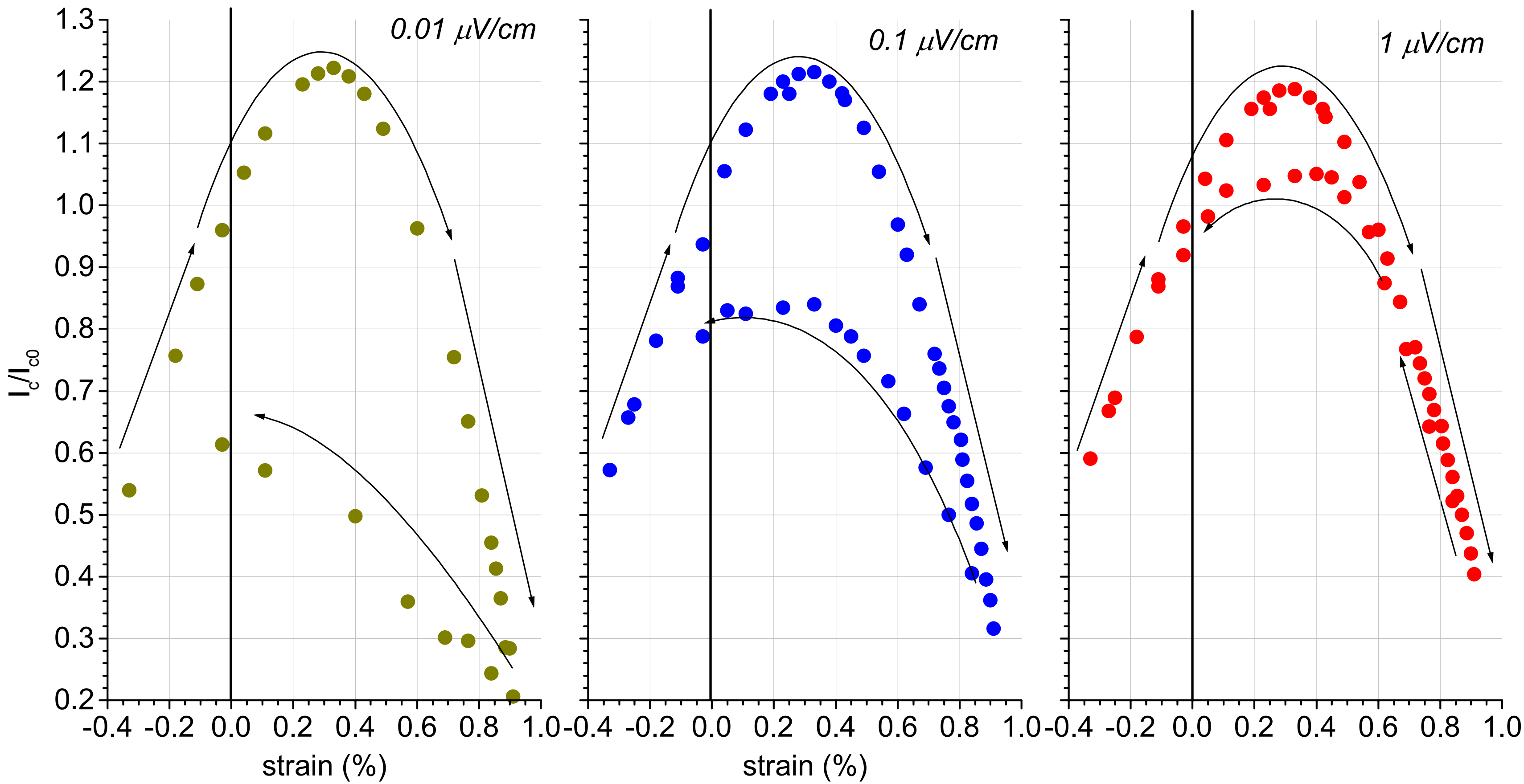
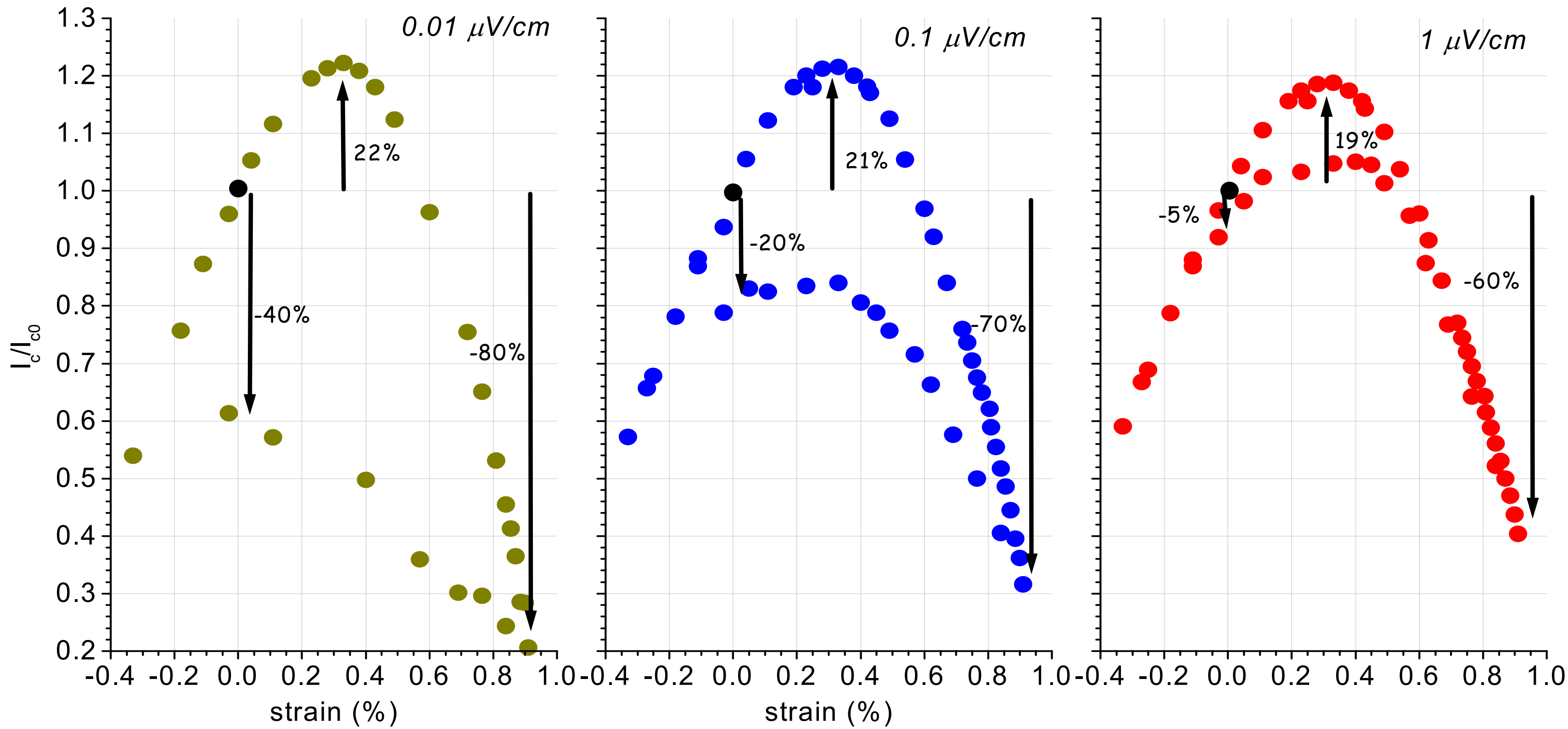
Furukawa for ITER, diam 0.8mm
360°C/5h - 460°C/30h - 650°C/240h

d = 26 cm - 4.2K - 13 T



Furukawa for ITER, diam 0.8mm
360°C/5h - 460°C/30h - 650°C/240h

d = 26 cm - 4.2K - 13 T



•I_c does not depend on the criterion for strain up to 0.6%/0.7%.

•After strain is released, I_c depends strongly on the criterion

<u>the irreversible strain limit depends on the I_c criterion</u>

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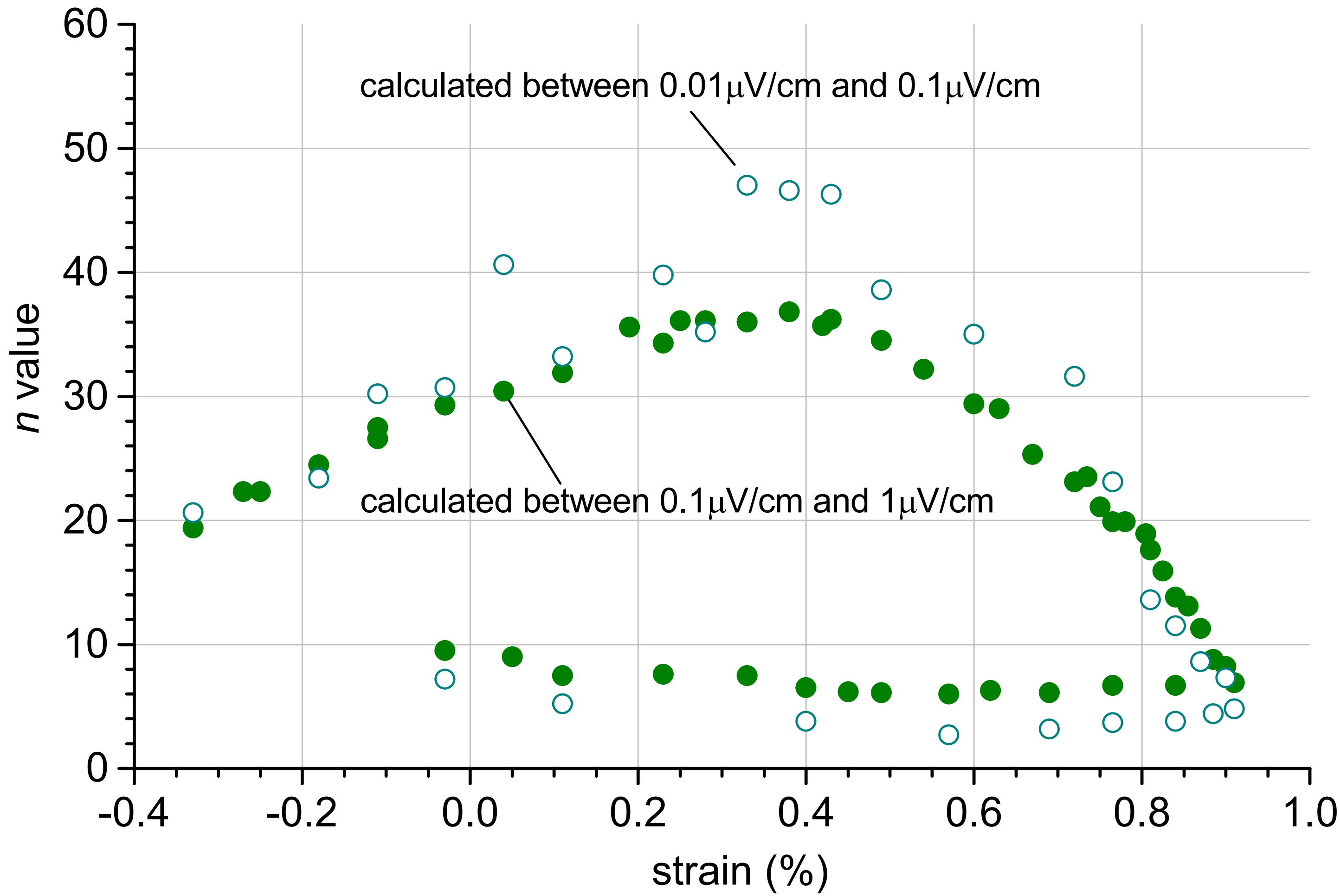
Furukawa for ITER, diam 0.8mm
360°C/5h - 460°C/30h - 650°C/240h

d = 26 cm - 4.2K - 13 T



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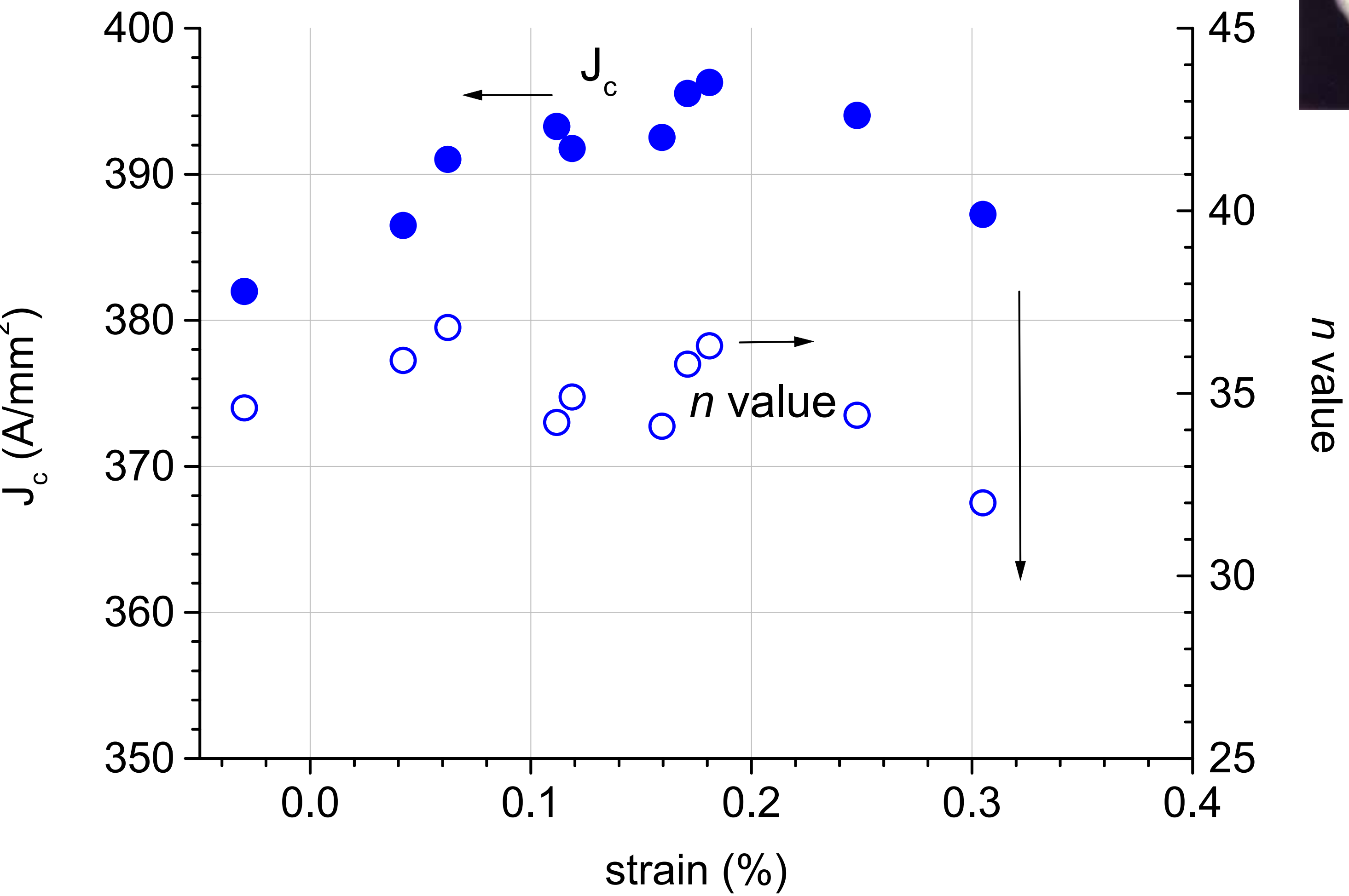
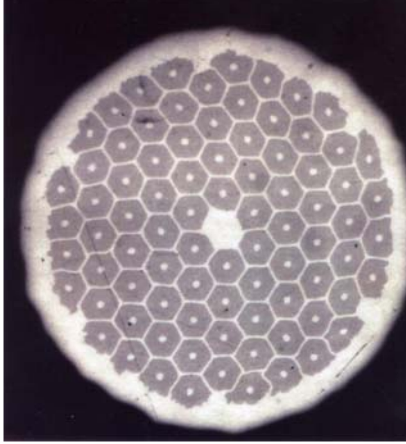
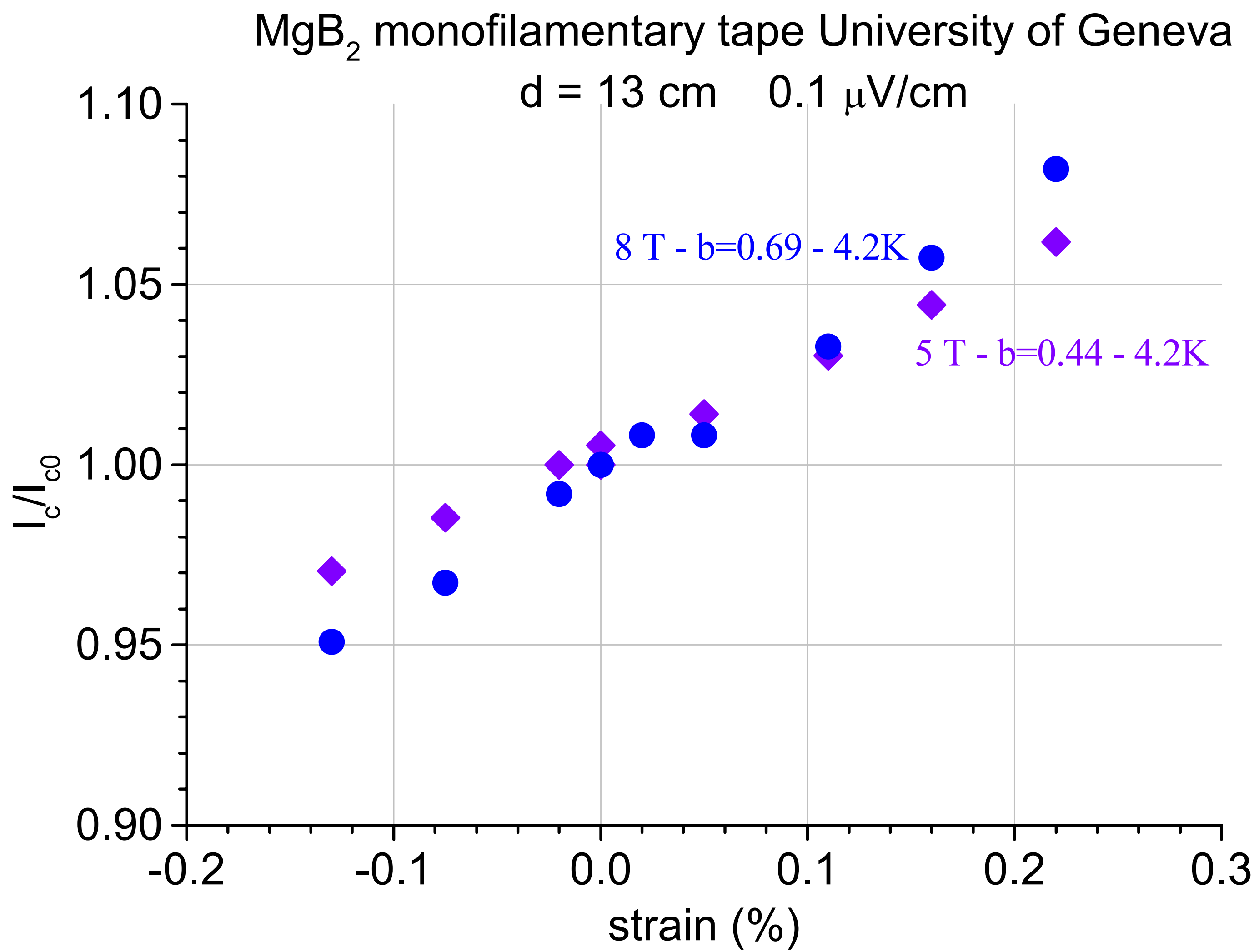
4.2K - 17T

0.1μV/cm

Nb_3Al wire







MgB2 monofilamentary tape University of Geneva
d = 13 cm 0.1 μV/cm
8 T - b=0.69 - 4.2K
5 T - b=0.44 - 4.2K
Ic/Ic0
1.10
1.05
1.00
0.95
0.90
-0.2
-0.1
0.0
0.1
0.2
0.3
strain (%)

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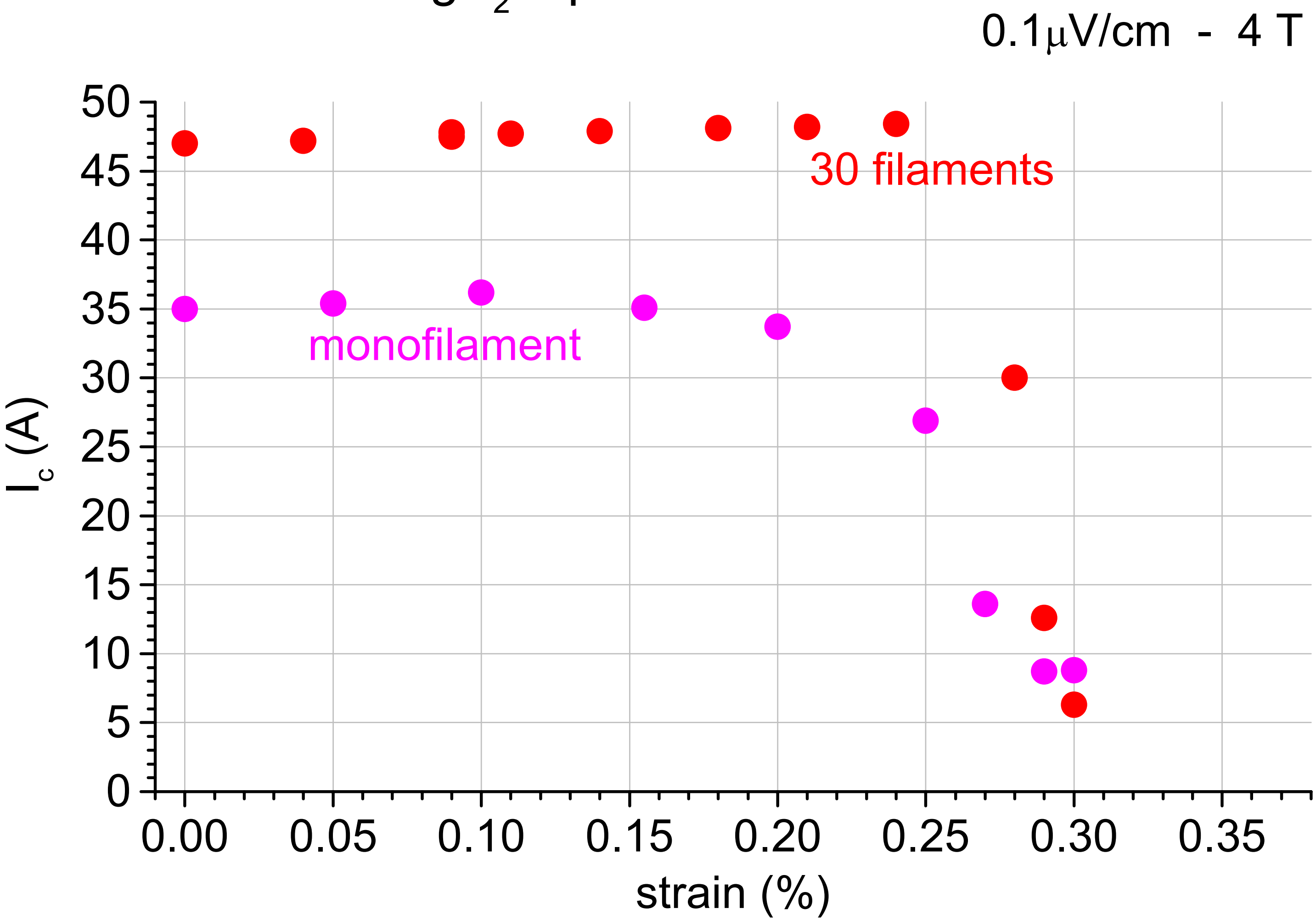
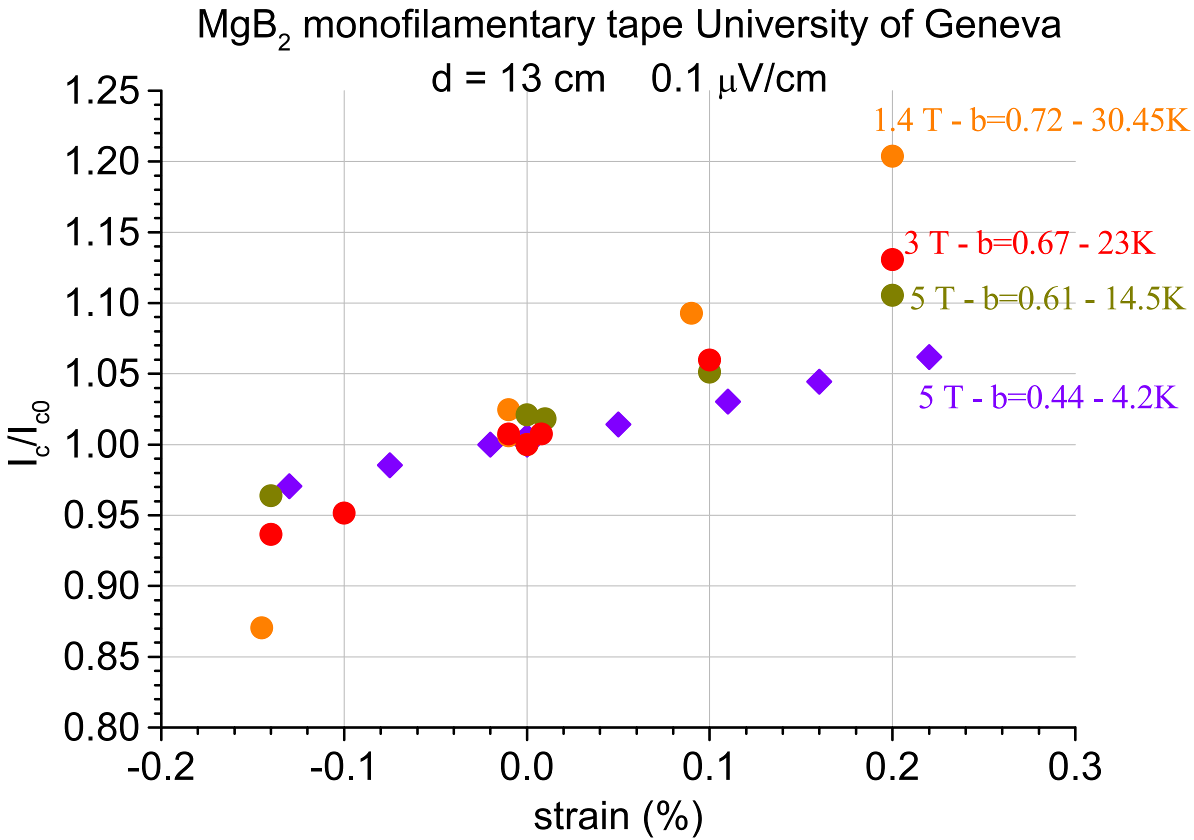
Columbus MgB_2 tapes





ε=+0.2% B_{irr}=+2.9%

ε =-0.3% B_{irr}=-3.2%

ε =+0.2% T_c=+0.2%

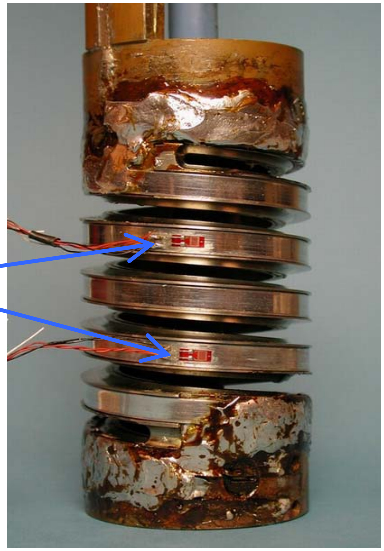
ε =-0.2% T_c=+0.2%

Mounting procedure

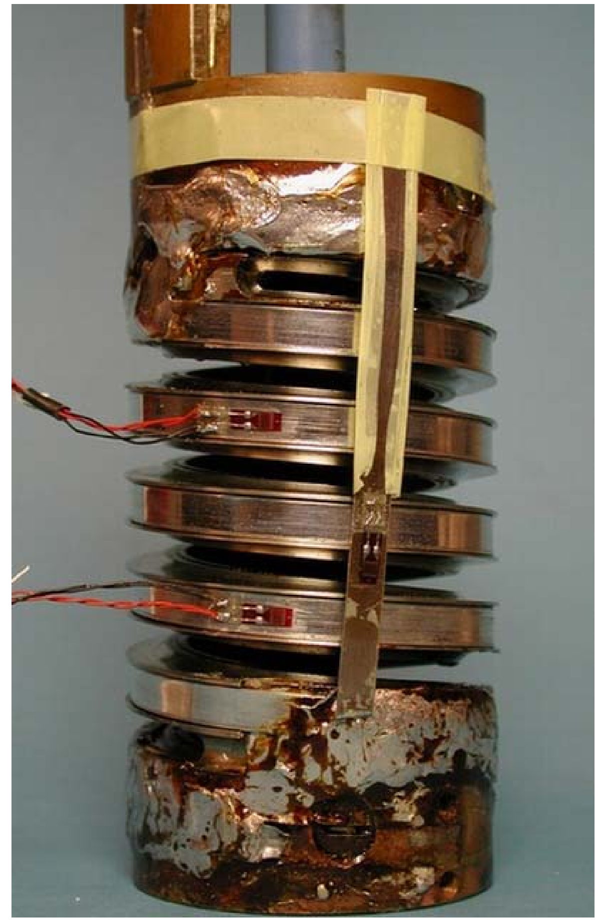
Some materials, like Nb_3Al and Bi2223 do not exhibit a bell shape $I_c(\varepsilon)$, so the pervious procedure can not be used.

the tape is wound tightly on the WASP

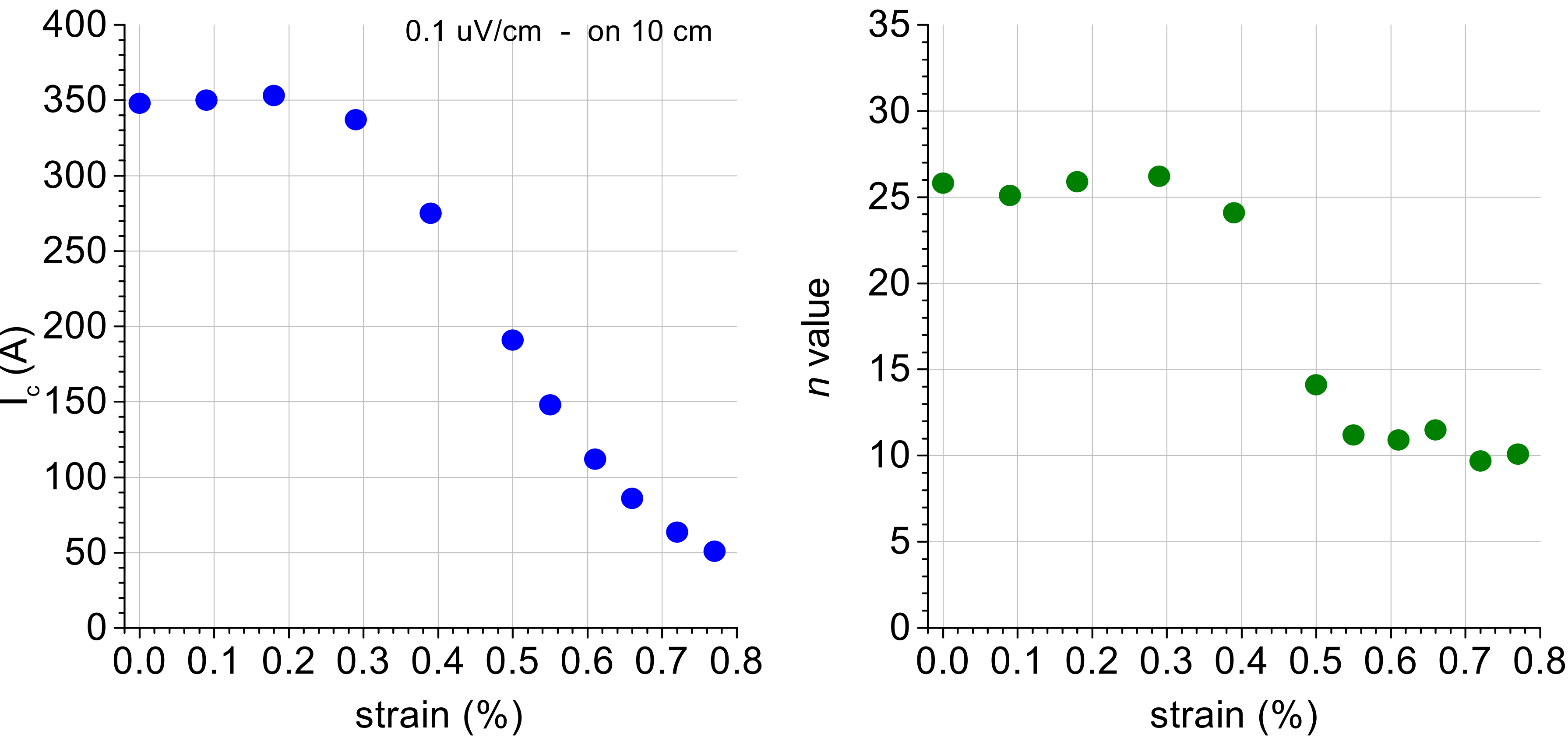
strain gauges



reference tape



ASC Bi2223 3-ply tape
4.2 K - 15 T



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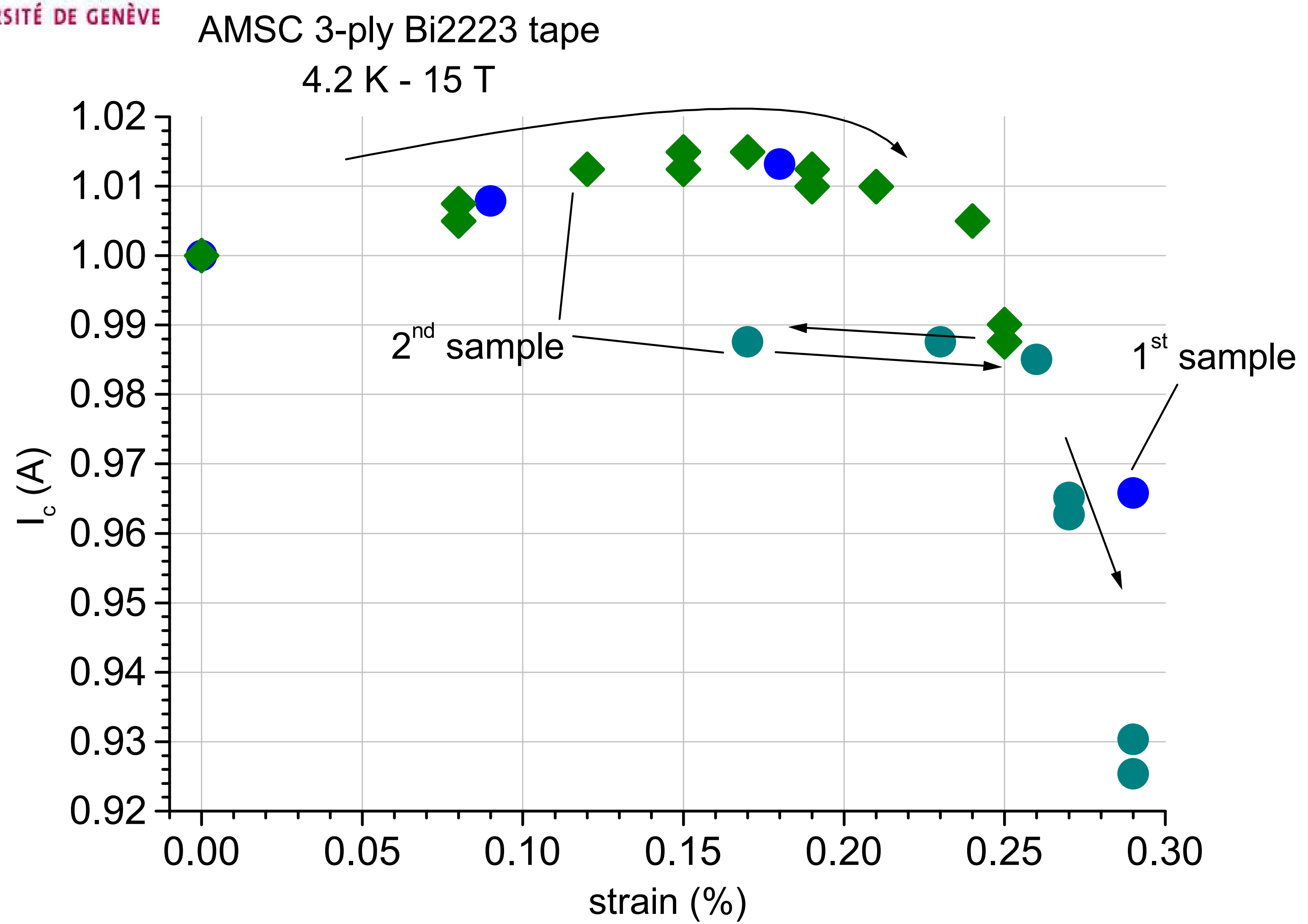


Conclusions

We have a developed a device to measure critical current of technical superconductors (wires and tapes) under strain up to 1000 A and 17 T (soon 21 T).

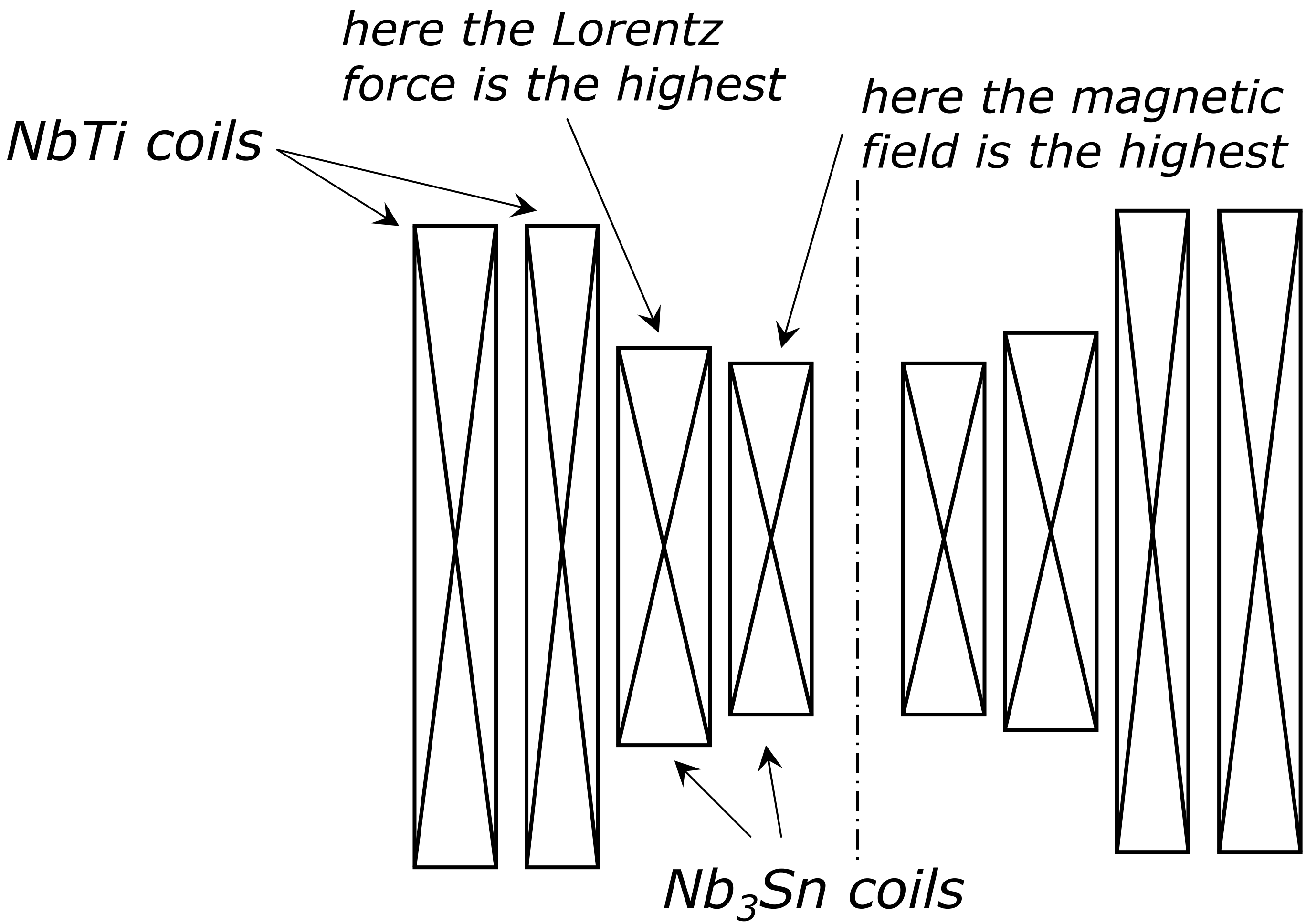
specifications:

- **max current 1'000 A**
- **wire length up to 1 meter**
- **max voltage taps distance 50 cm**
- **I_c criterion 0.01μV/cm**
- **field up to 17T (sonn 21T)**
- **measurement of ε_m**

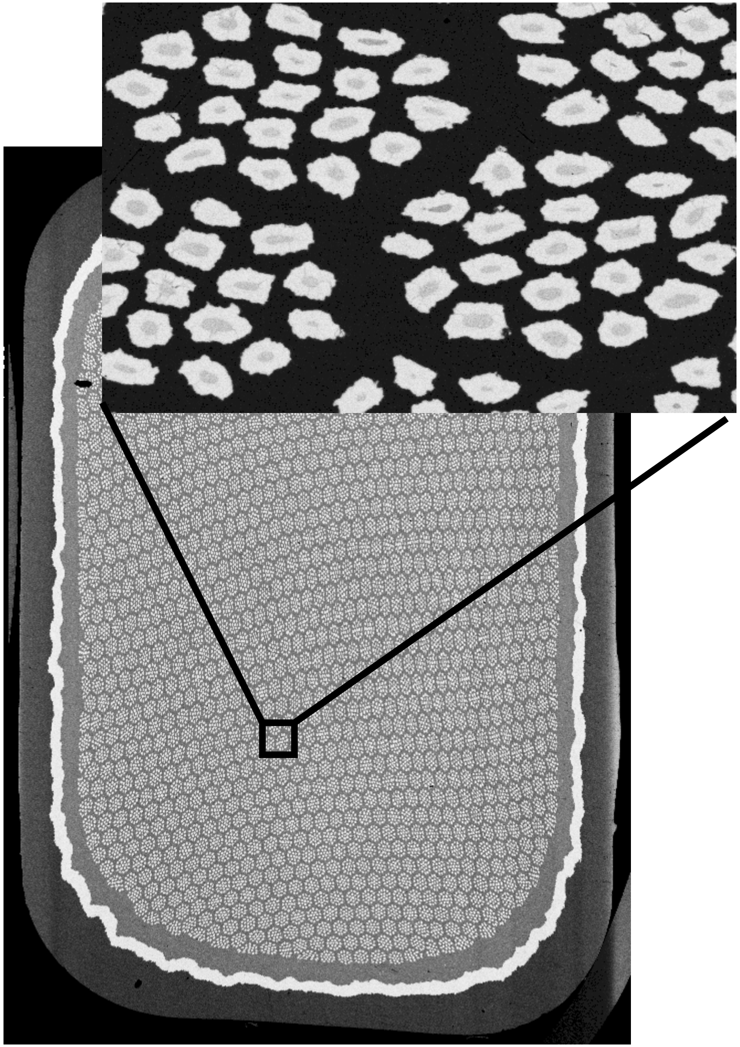

BRUKER
800
US2

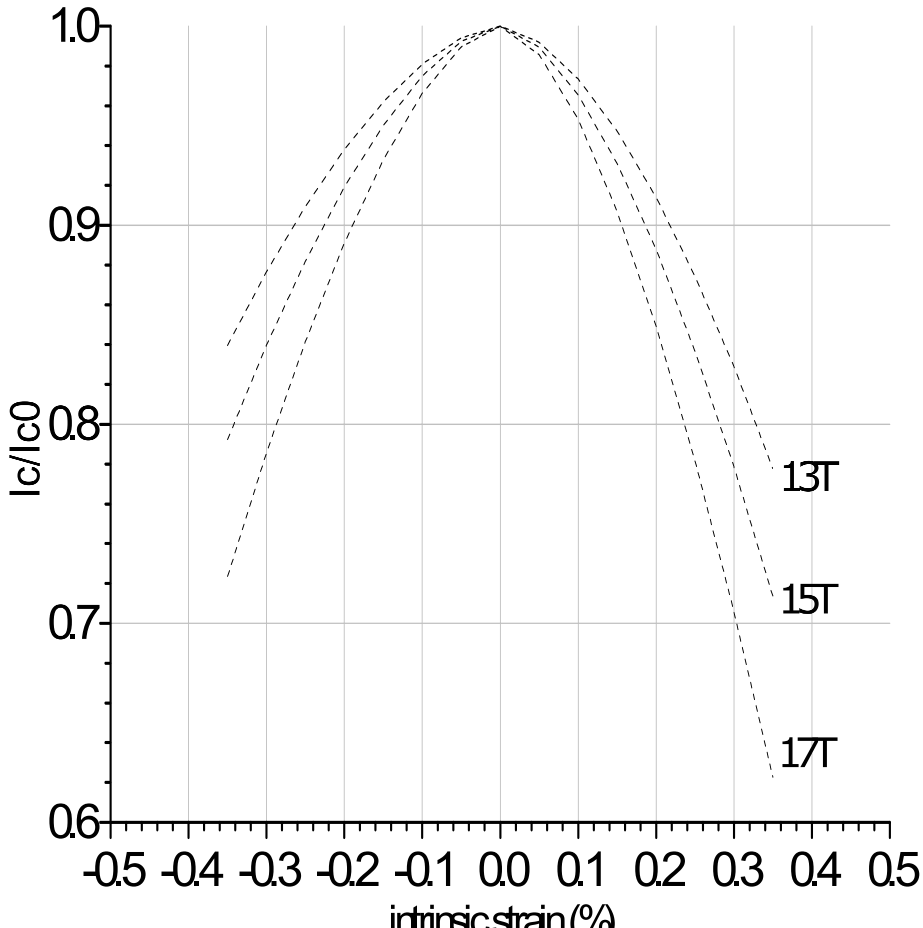

BRUKER
800
US2

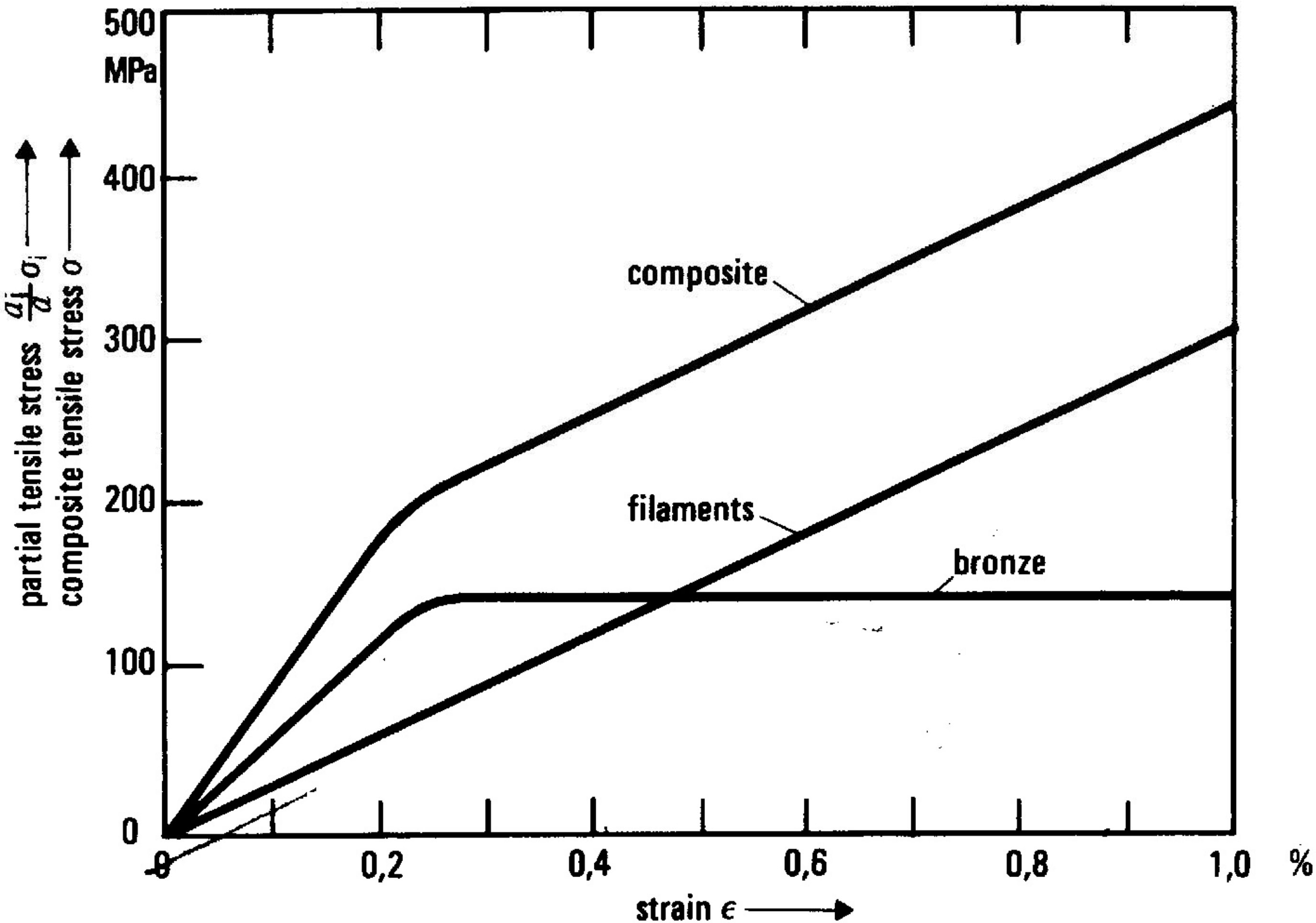
High field magnet design



Nb_3Sn mechanical properties







from G. Rupp, in "*Filamentary A15 Superconductors*", pp.155, edited by M. Suenaga and A. F. Clark, 1980