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5T class superconducting bulk magnet using MgB_2 bulk doped with Ti

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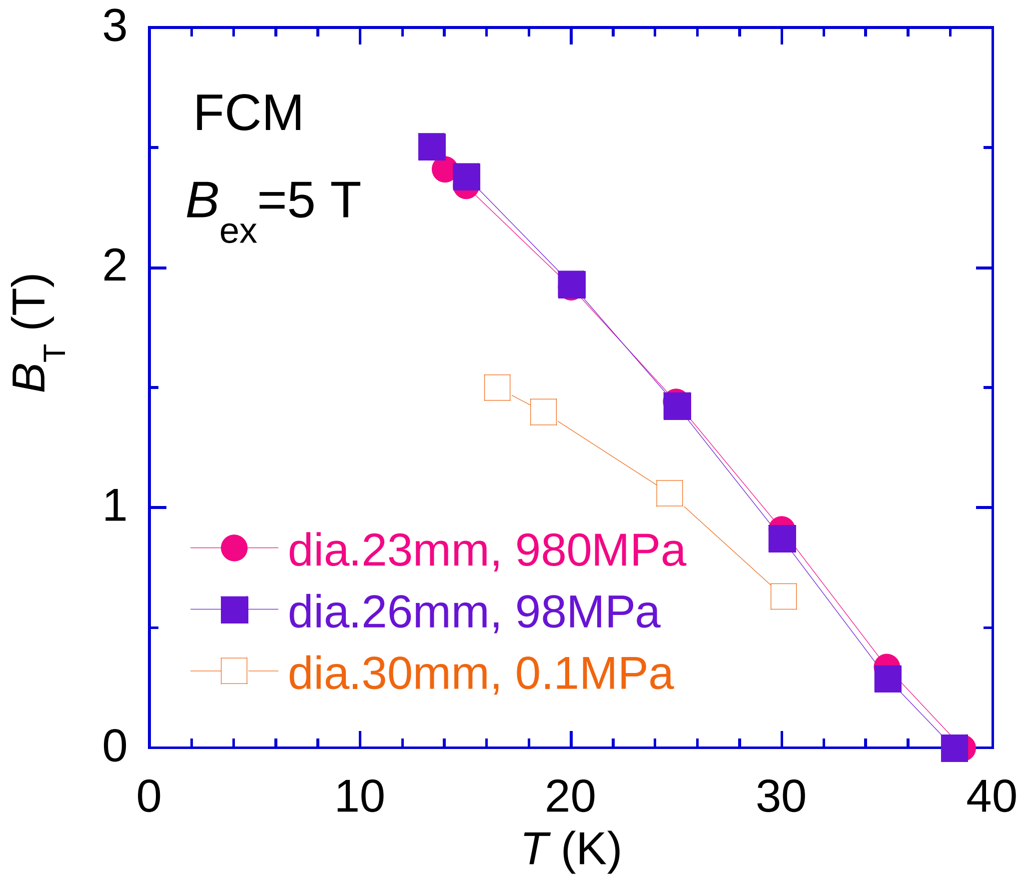
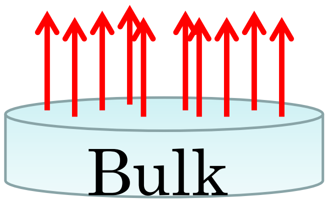
Introduction（our works）

■Development of MgB_2 superconducting bulk magnets.
(Quasi-permanent magnet)



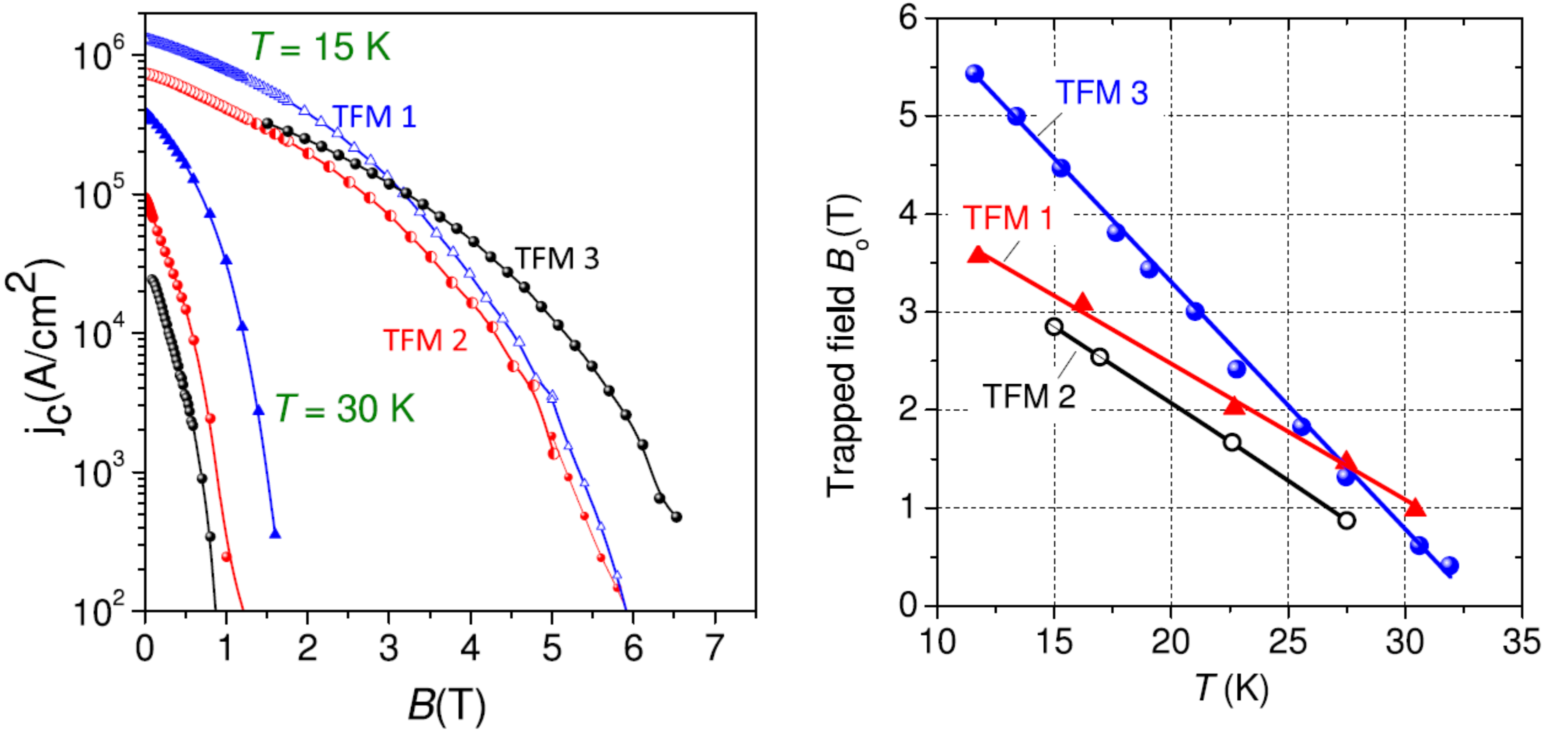


Tesla-class MgB_2 bulk magnets has been successfully obtained !
→To get higher B_T, the pinning force must be enhanced.

Grain refining

Grain boundaries (GBs) are flux pinning centers,
So their refining is expected to enhance the pinning force.

G. Fuchs et al.,
SuST 26 (2013) 122002



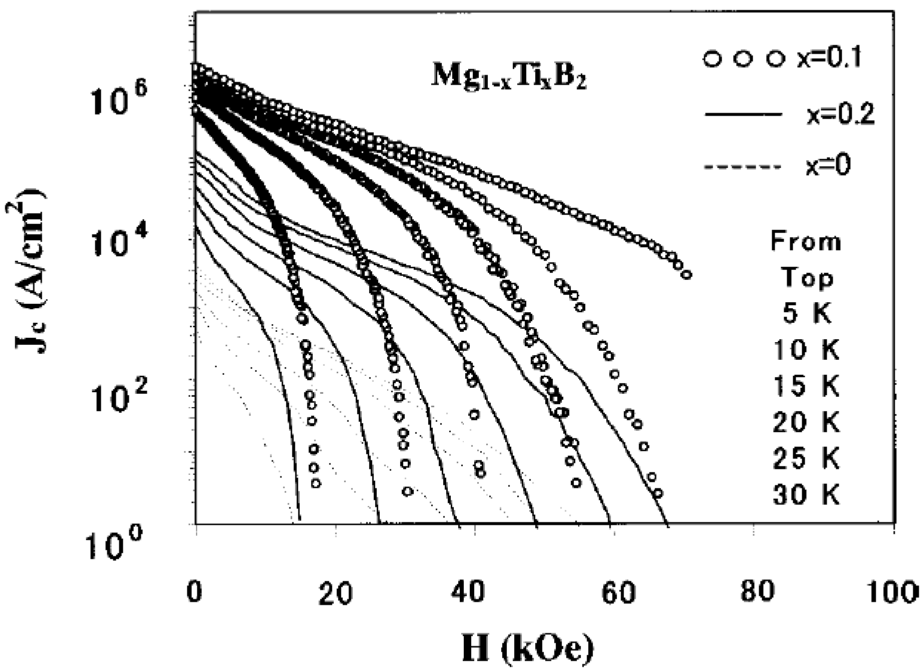
Hot pressed MgB_2 bulks using ball-milled powder were studied.

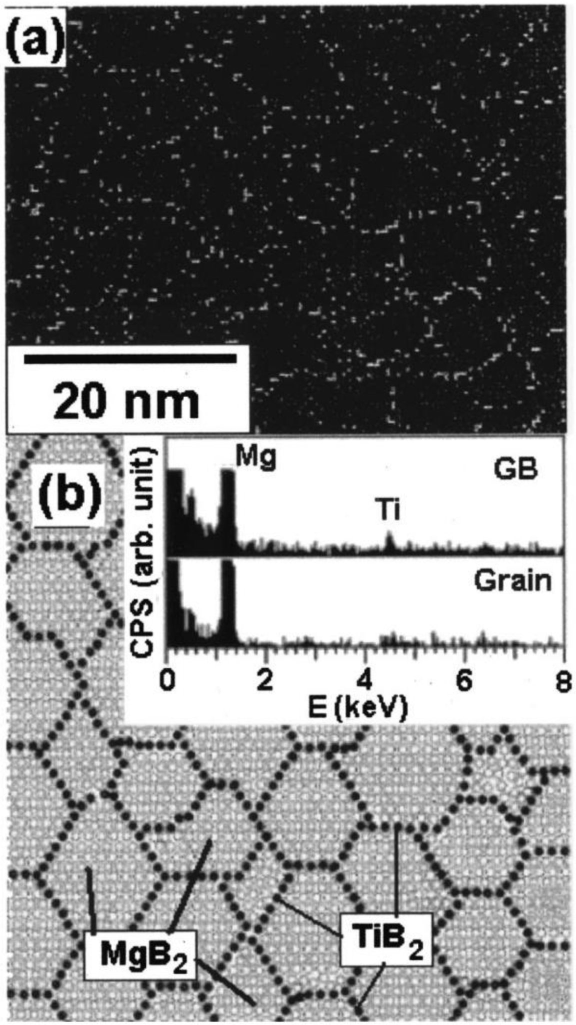
B_T=5.4 T@12 K was achieved.

Ti-doping

Impurity doping is an usual method to introduce pinning centers.
Ti and C are well known to be effective dopants.

Zhao *et al*., APL 79 (2001) 1154; 80 (2002) 1640





- Ti10% maximizes J_c.
- TiB_2 layer at GB act as pinning center.
- Ti-doping fines down MgB_2 grains.
  →densification

Objective

Literatures revealed that
Ti-doping is quite effective for the enhancement of J_c in magnetic fields and for the grain refining.

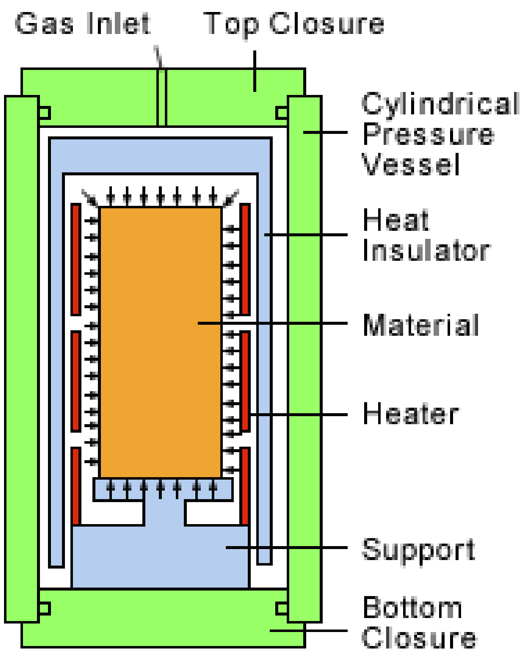
⇩

We examine an effect of Ti-doping on the trapped field and vortex pinning properties of MgB_2 bulks.

MgB_2 bulk preparation

in-situ HIP (Hot Isostatic Pressing) method

- Nominal composition : **$(Mg_{1-x}Ti_x)B_2$ (x=0.05, 0.1, 0.2).**
- Precursor pellet was sealed in SS container in vacuum.
- *in-situ* method: sintered at 900℃ for 3h under 98 MPa.



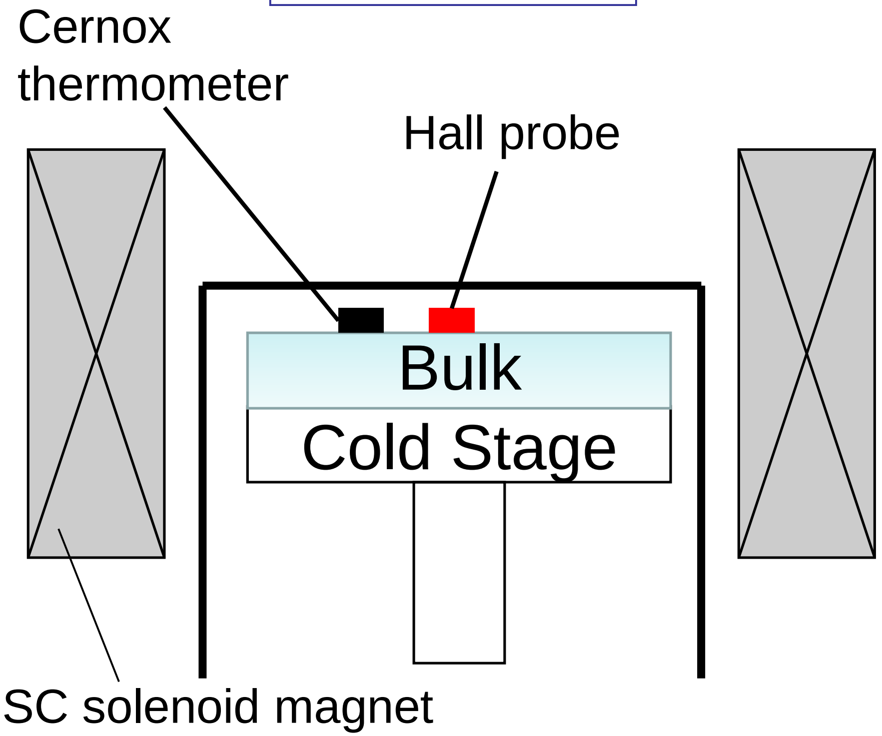
Schematic image of HIP machine
(from KOBELCO's HP)

Bulks	Diameter (mm)	thickness (mm)
HIP-Ti 5%	36	7
HIP-Ti 10%	36	7
HIP-Ti 20%	36	7
HIP-pristine	38	7

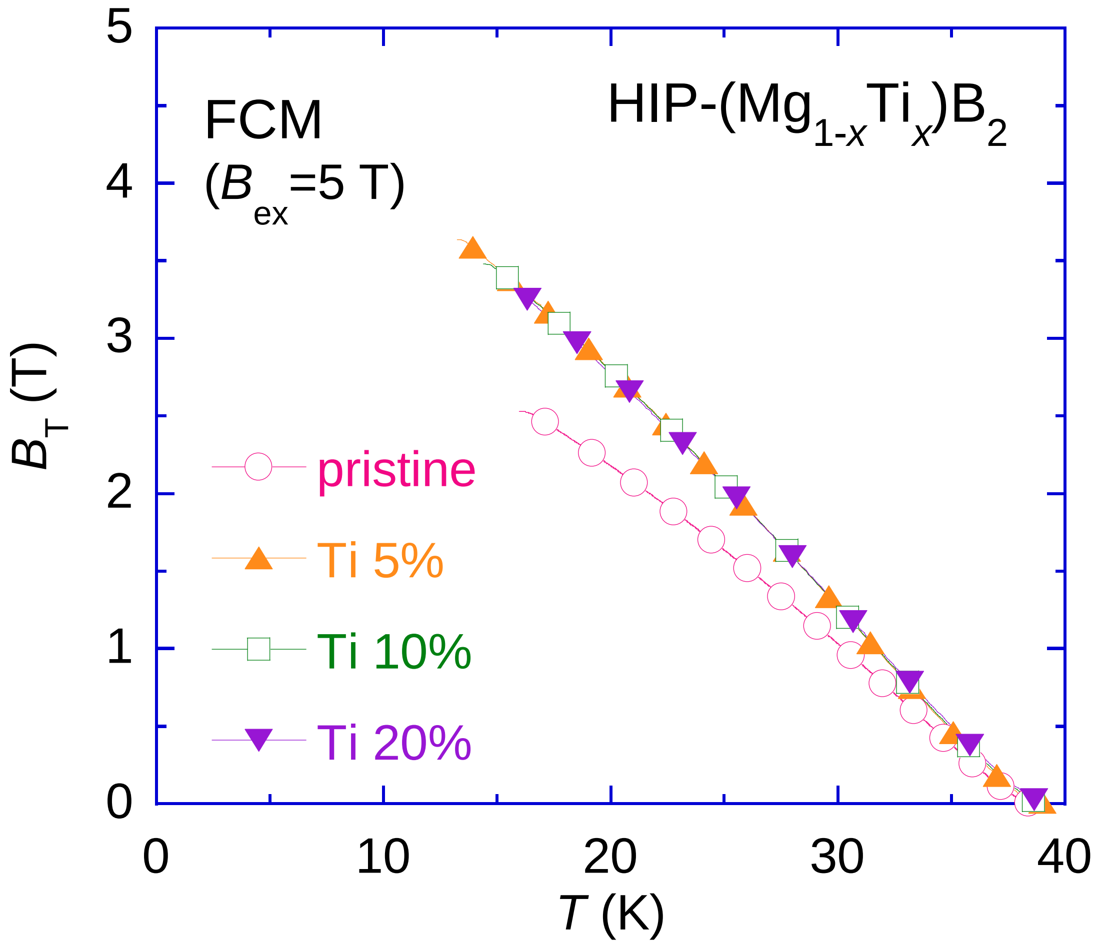
Measurements

- Trapped Field： Field cooled magnetization (FCM)
- Critical current density：Magnetic hysteresis loop by SQUID magnetometer and Bean’s model
- Phase evaluation：Powder X-ray diffraction
- Micro structure: EPMA, SEM

Set up for FCM



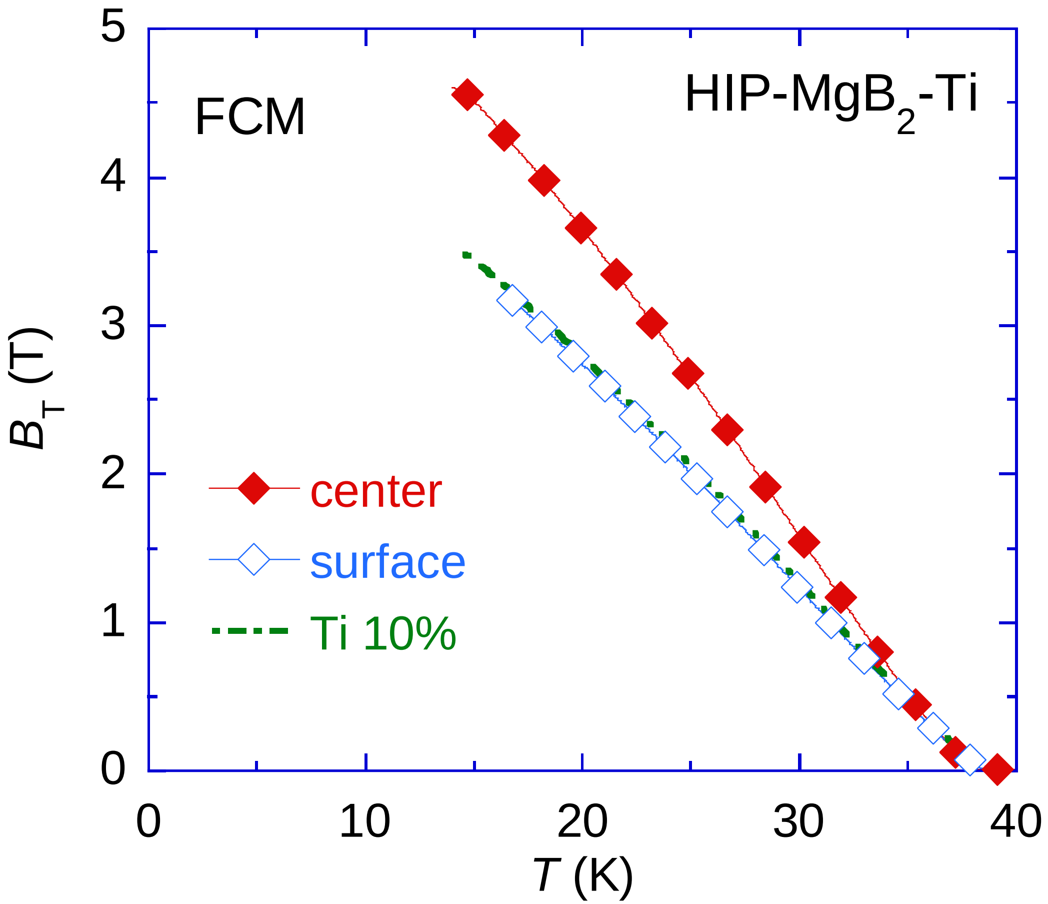
Ti-doping effect on B_T

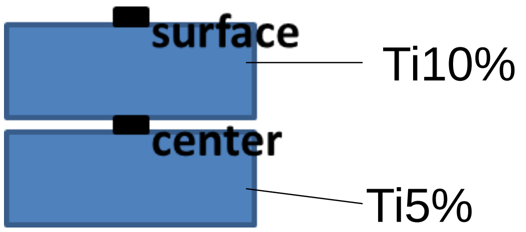


- Ti-doping enhances B_T by 1.3 times.
  (**2.7 T→3.6 T@13.4 K**)
- B_T is not sensitive to the Ti contents.

Stacked bulk

To eliminate the demagnetization effect,
We measure the B_T of the stacked bulk which consists of Ti 5% and 10% bulks.



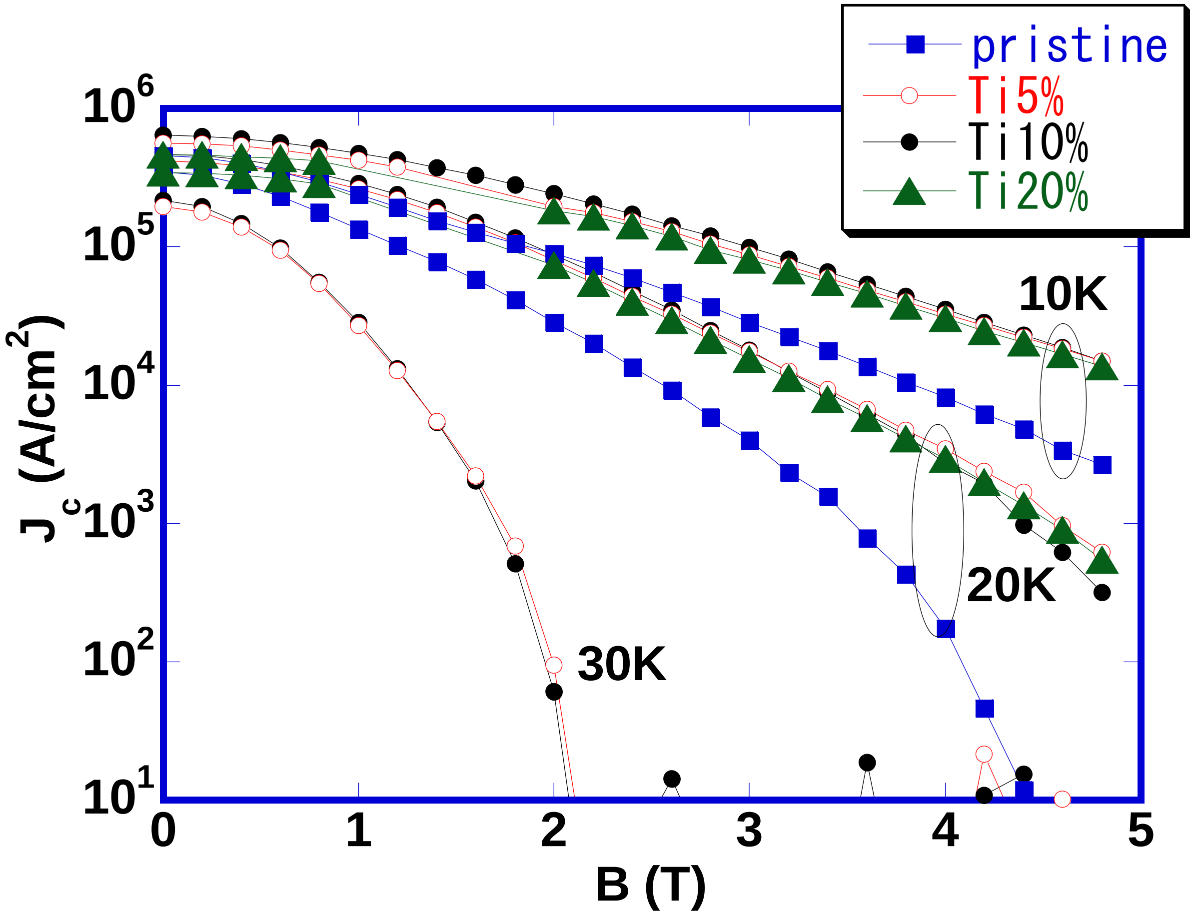


■Max. of B_T

- **center**: **4.6 T@14.1 K**
- **surface**: **3.2 T@16.3 K**

1.3 times larger against for a single bulk

Critical current density

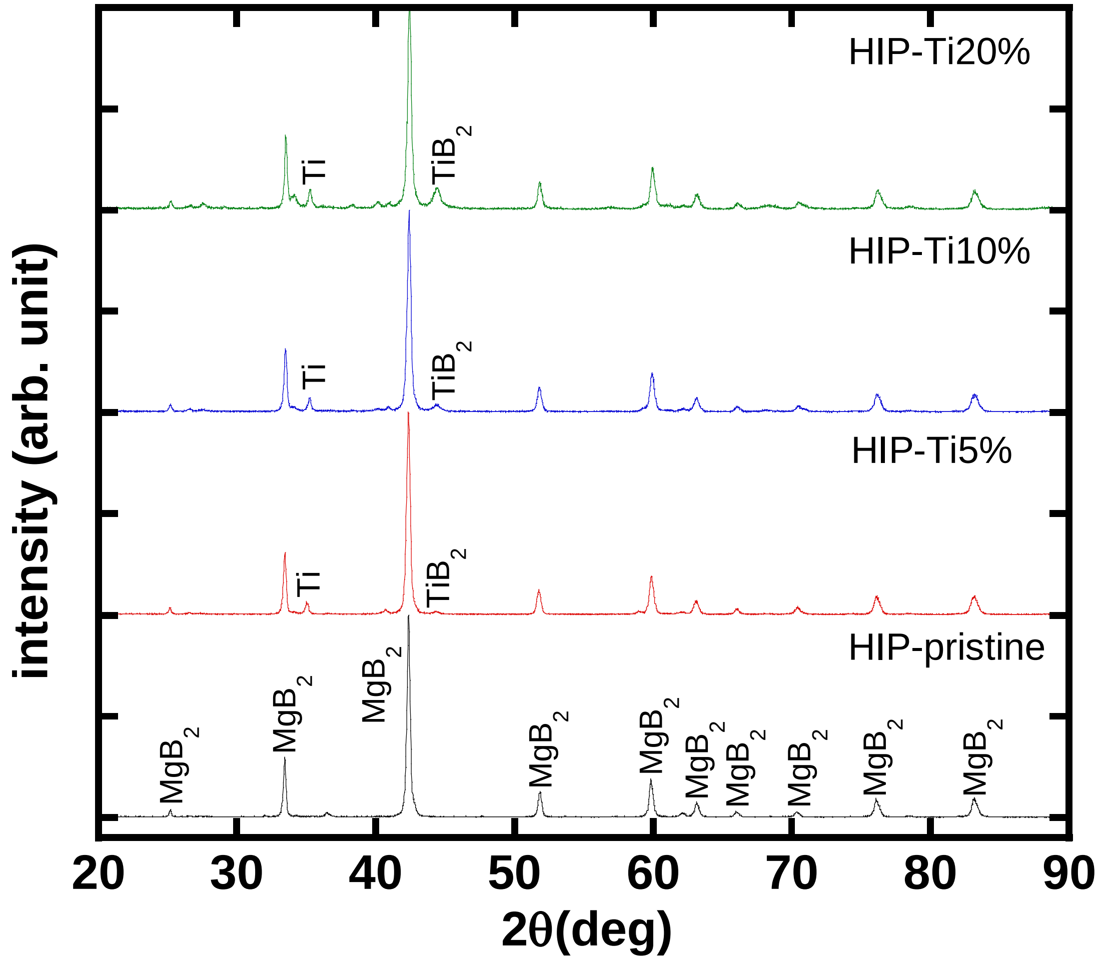


- Ti-doping enhances J_c.
- J_c hardly depends on the amount of Ti.

consistent

<u>Result of B_T properties</u>

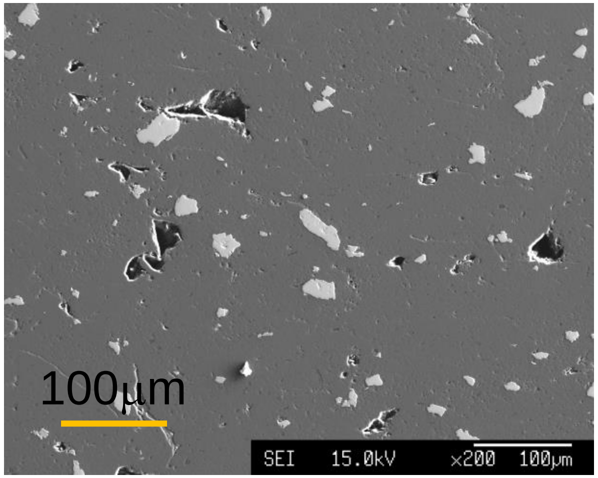
XRD



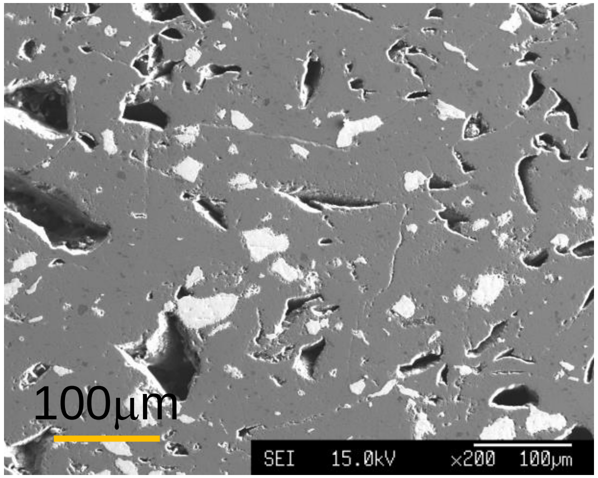
- Impurity phases of **Ti** and **TiB_2** are observed in Ti-doped bulks.
- Their intensity increases with Ti-doping.

SEM Images

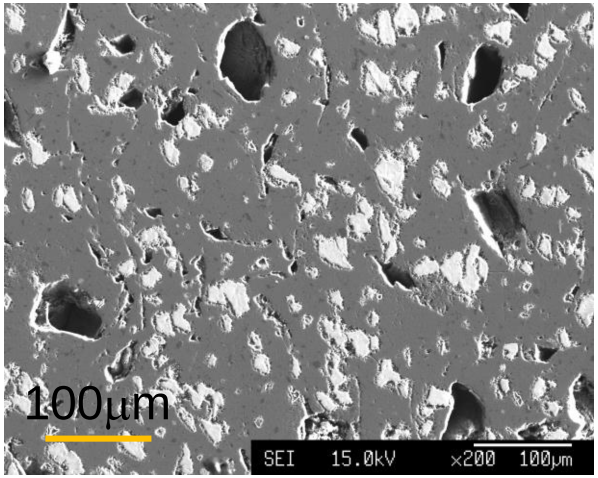
Ti5%



Ti10%



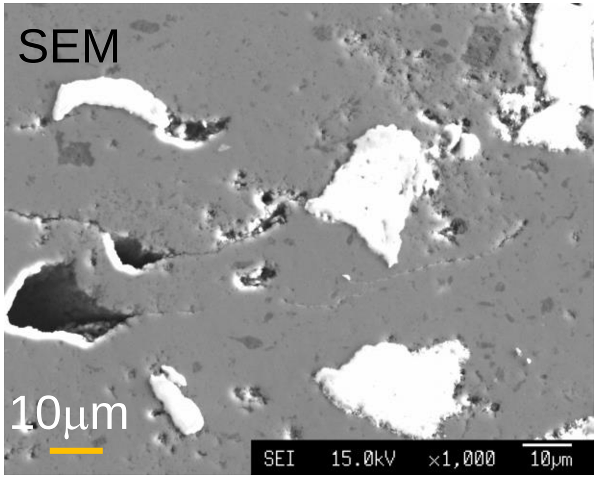
Ti20%



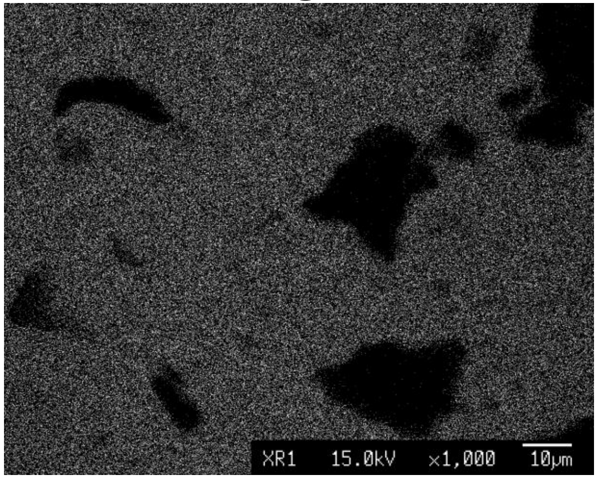
White regions (maybe Ti eduction) obviously increase with Ti-doping, which is consistent with XRD results.

Characteristic x-ray image

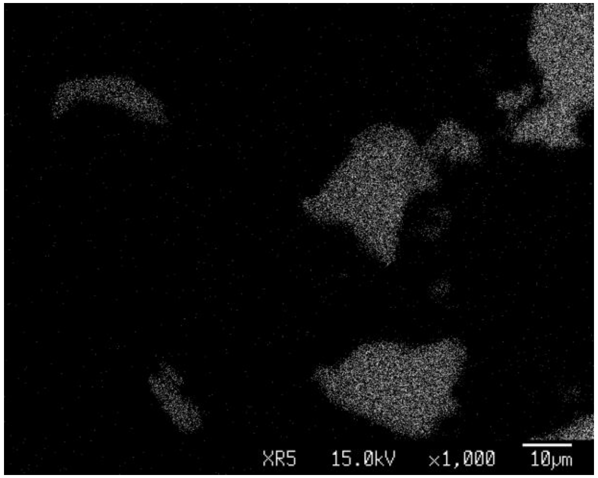
■Ti10%



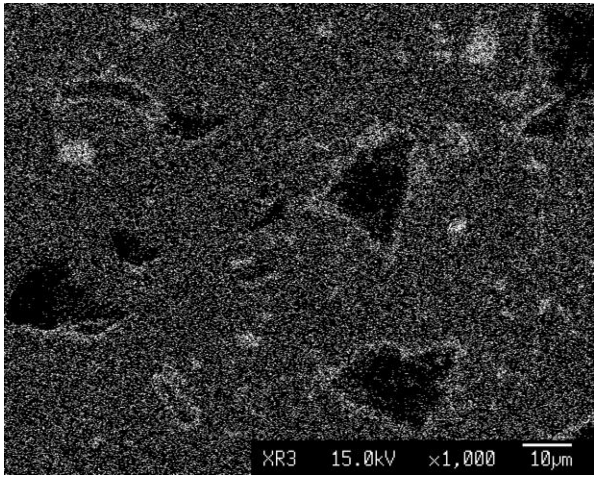
Mg



Ti



B



- Size of Ti eduction is approximately 10 μm order.
- B exists around Ti→TiB_2(?) acts as a pinning center.

Summary

To obtain a higher trapped magnetic field of MgB_2 bulk, we examined an effect of the Ti-doping.

■Ti-doping enhanced the critical current density(J_c) and the trapped field(B_T).

- B_T of Ti-doped bulks are 1.3 times larger than that of the pristine bulk.
- The highest B_T at the center of the stacked bulk was **4.6 T**, which is 1.3 times larger than that of the single bulk.
- B_{irr} at 20K of Ti-doped bulks exceeds 5 T.
- Macroscopic behaviors are not sensitive to the amount of Ti

Inconsistent

Further studies are needed !

■Microscopic analysis

- Ti and/or Ti compounds increases with Ti-doping.
- B was concentrated around Ti →TiB_2 acts as a pinning center, which enhances J_c and B_T.

Acknowledgements:

Hidekazu Teshima (Dr.) of
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*

Why MgB_2？

■Advantages of MgB_2 bulk for application

・Light weight

→ MAGLEV train (energy save),

Wind power generator (supporting material save)

・Weak-link free (due to long coherence length)

→ polycrystalline bulk is applicable

→ homogeneous, easily enlargement

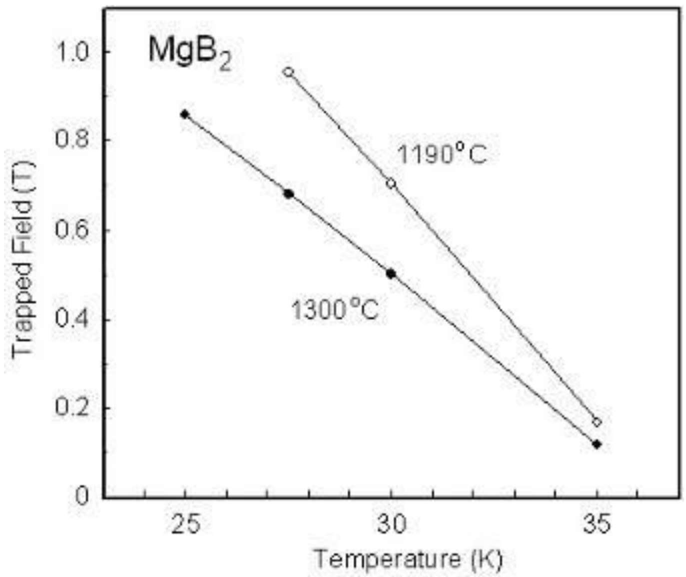
・Relatively high T_c (~39 K) → cryo-cooler cooling

・High yield stress → reinforcement-free

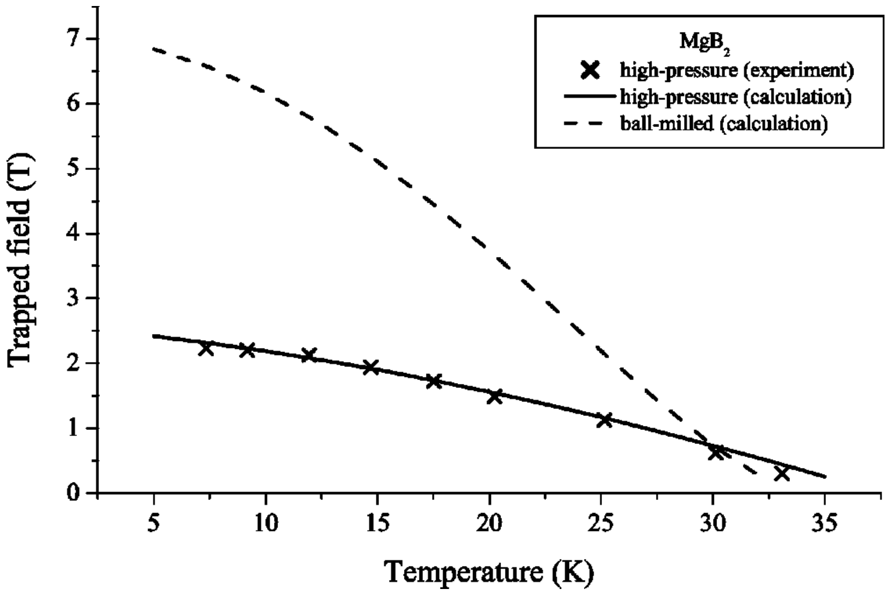
★2~3 times larger than REBCO bulk

A. Murakami@Ichinoseki National College of Technology, (Private communication)

Reports on MgB_2 bulk magnet



Murakami, Yoo et al.,
SUPERCOM, Vol.12, No.5, Oct. **2003**



Viznichenko *et al.*: Appl. Phys. Lett. **83** (**2003**) 4360

- **1T**@27.5K (30mmφ)
(Spark Plasma Sintered bulk)

- **2.3T**@6K (28mmφ)
(High pressure (2GPa) sintered bulk)

・・・Recently,
MgB_2 bulk magnets come into the spotlight again.

Many presentation are found in this conference !