

"Virtual CCA 2021"
"21st anniversary"

NM-5

SuNAM's Coated Conductor Development for NMR/MRI Applications



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SuNAM Co., Ltd.

Oct. 13, 2021.

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- What SuNAM is doing

- SuNAM's coated conductor
 - CC architecture & process
 - RCE-DR process for superconducting layer
 - Quality control → Uniform, high- I_C tapes

- New RCE-DR system
 - Introduction of pinning center; mid-T, mid-B I_C enhancement
 - Preliminary results on various RE's other than Gd

- Summary

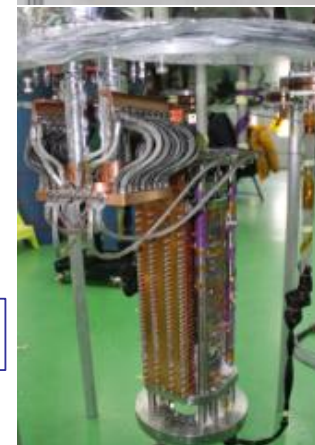


What SuNAM is doing

2G HTS Tapes



High Field Magnets



18 T Research Magnet

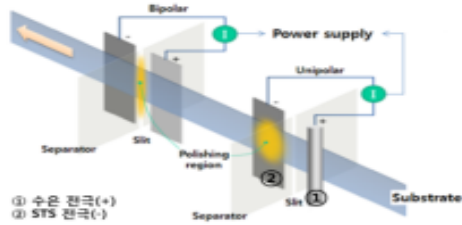
400 MHz NMR Magnet



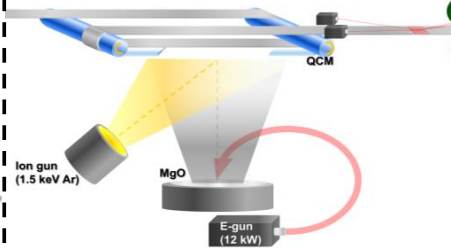
HTS 2G Wire Process of SuNAM



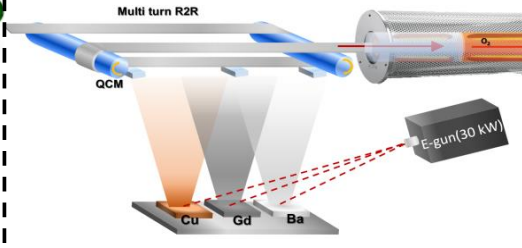
Electro polishing



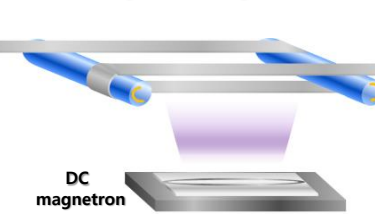
IBAD (Buffer layers)



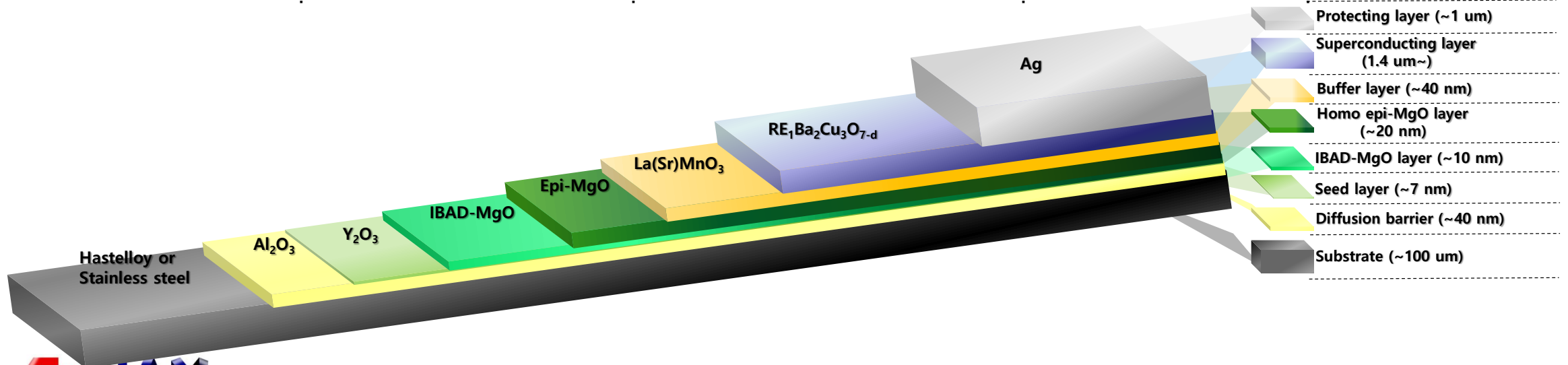
RCE-DR (Superconducting layer)



Ag coating



CCs

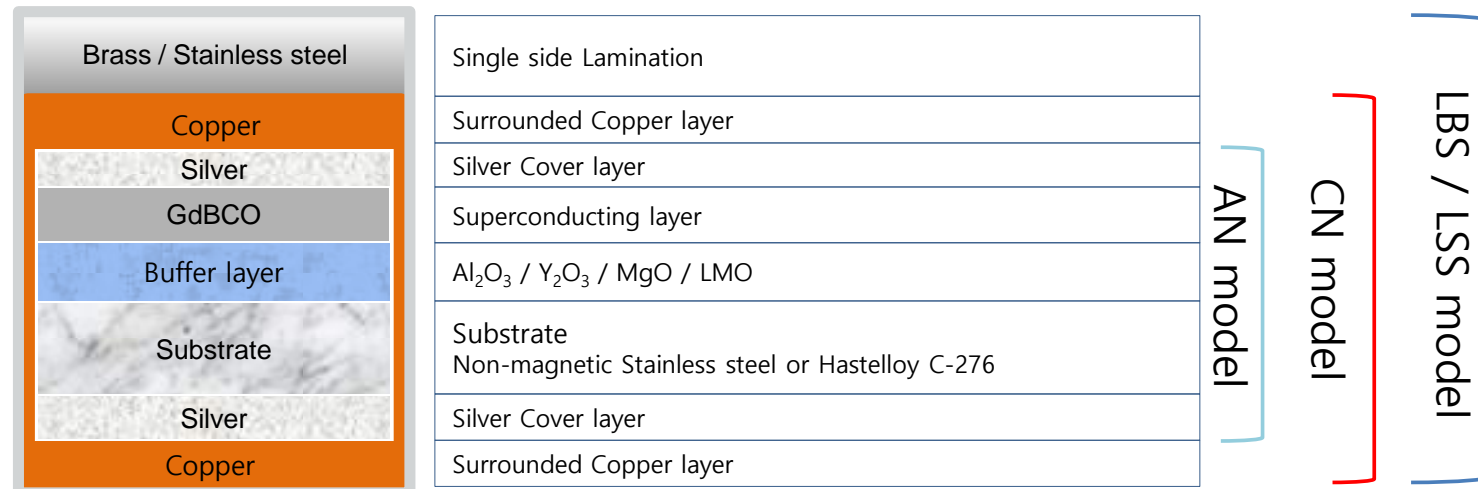




Product Portfolio

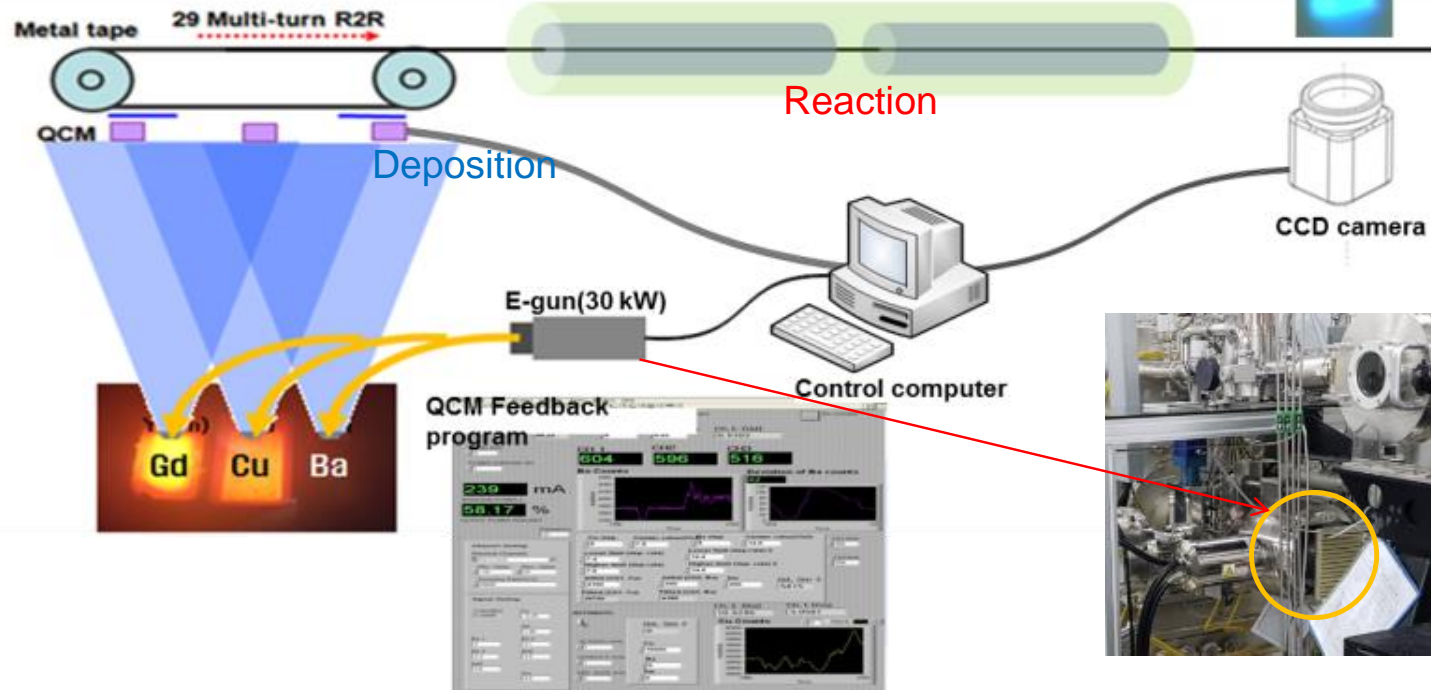
[2G HTS wire portfolio]

Item	AN	CN	LBS / LSS
Cover layer	Silver	Copper	Brass / Stainless steel
Substrate	Non-Magnetic Stainless steel (STS310S ~104 um) or Ni-alloy (Hastelloy C-276 ~ 62 um)		
Width [mm]	4 / 12 standard width 2/3/5/6/7/8/9/10 special order		
Thickness [mm] *depending on Substrate	HAS : 0.10 STS : 0.14	HAS : 0.10 STS : 0.14	STS substrate only LBS : 0.29 / LSS : 0.23
Final Process	Sputter	Electro-plating	Single side Lamination
Critical Current (@ 77K s.f.)	4 mm width : > 150 A, 200 A, 250 A 12 mm width : > 500 A, 600 A, 700 A, 800 A		



* Not to scale

RCE-DR for Superconducting Layer Deposition

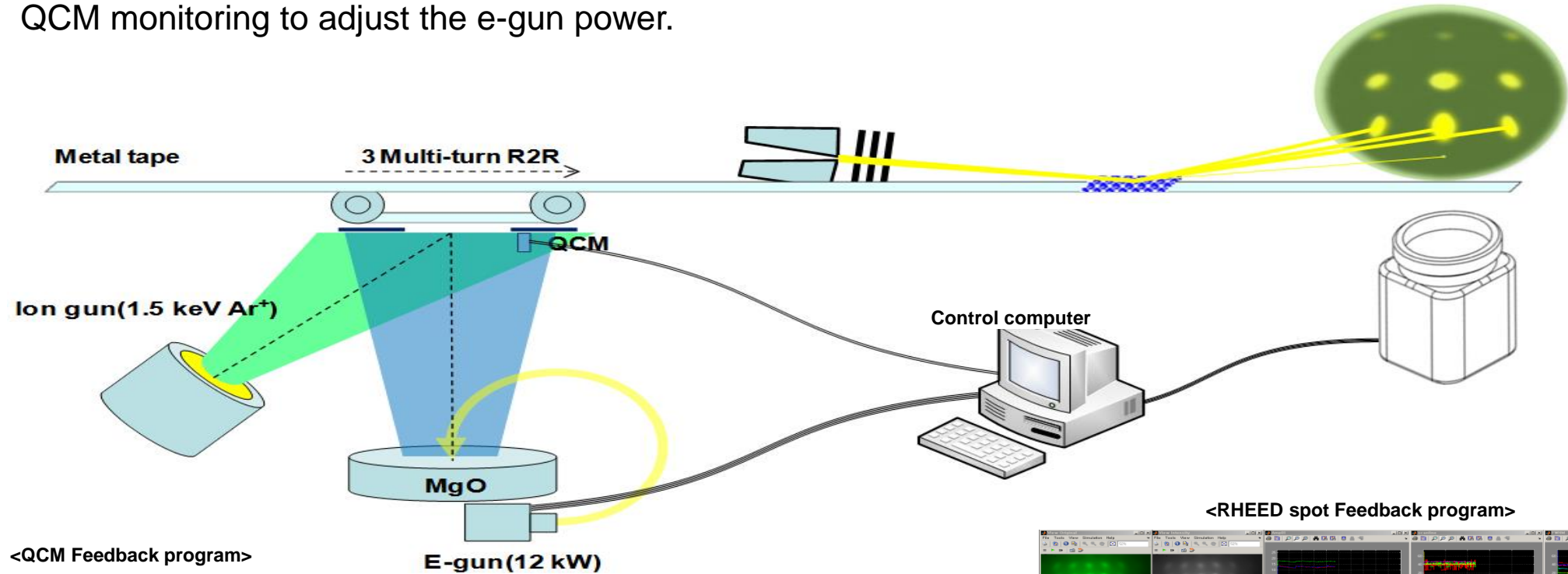


- RCE-DR : Reactive Co-Evaporation by Deposition & Reaction (SuNAM, Reel-to-Reel)
- High rate co-evaporation at low temperature & pressure to the target thickness(> 1 μm) at once in deposition zone (6 ~ 10nm/s)
- **Fast conversion**(up to 100 nm/sec) from **amorphous glassy phase** to **superconducting phase** at high temperature and oxygen pressure in reaction zone
- **Simple, high deposition rate, large deposition area...**
- **Easy to scale up** :single path
- Verified for Gd, Y, Sm, Pr ...

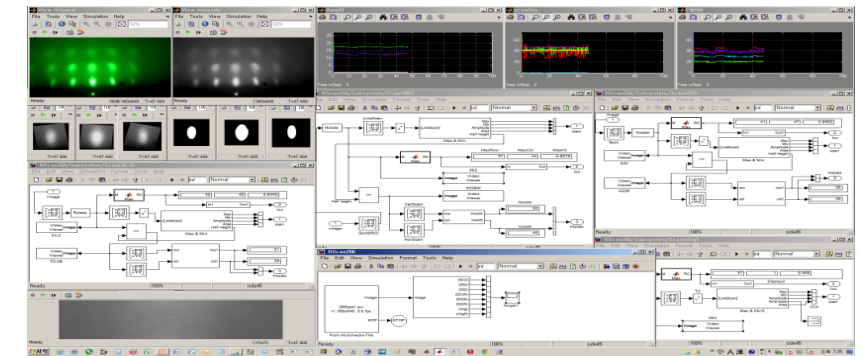
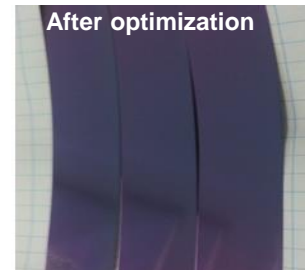
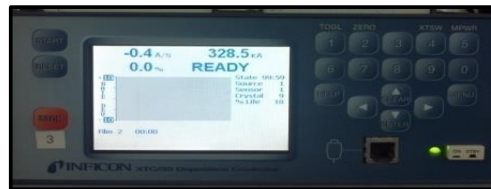


Quality Control : RHEED Vision System

- An appropriate feedback algorithm can keep the shape of the RHEED spot in the specific range, while QCM monitoring to adjust the e-gun power.

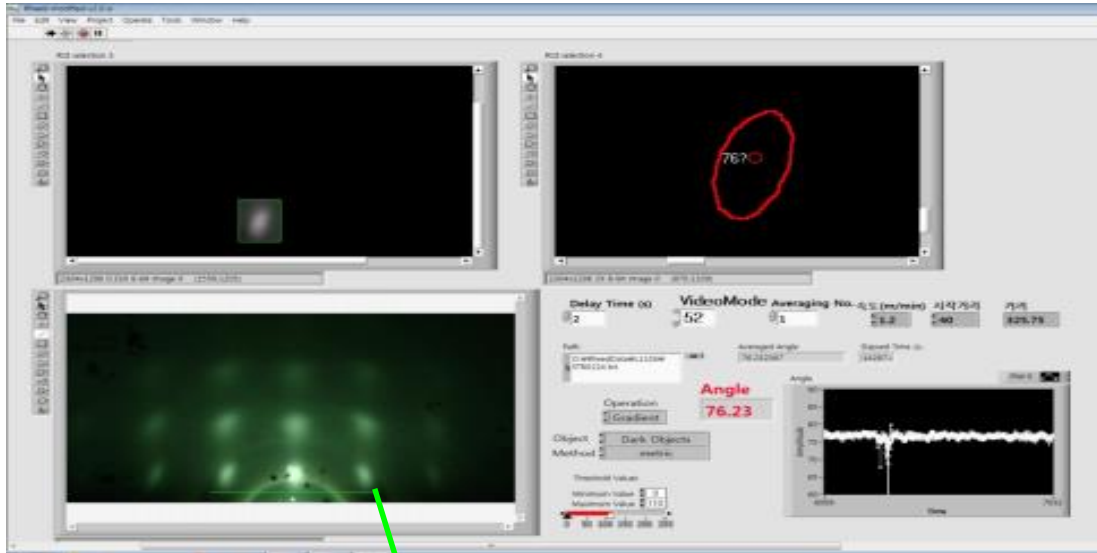


<QCM Feedback program>



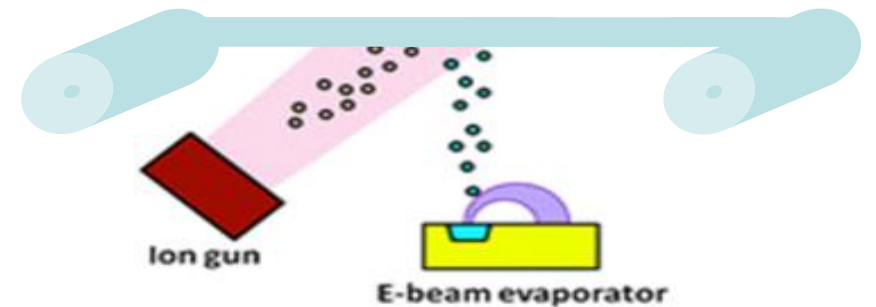
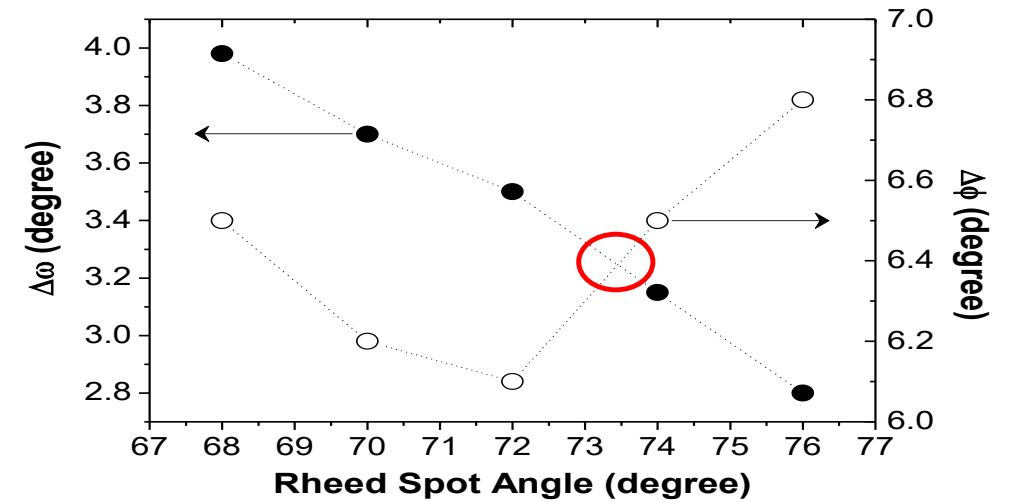


Feedback based on RHEED spot analysis

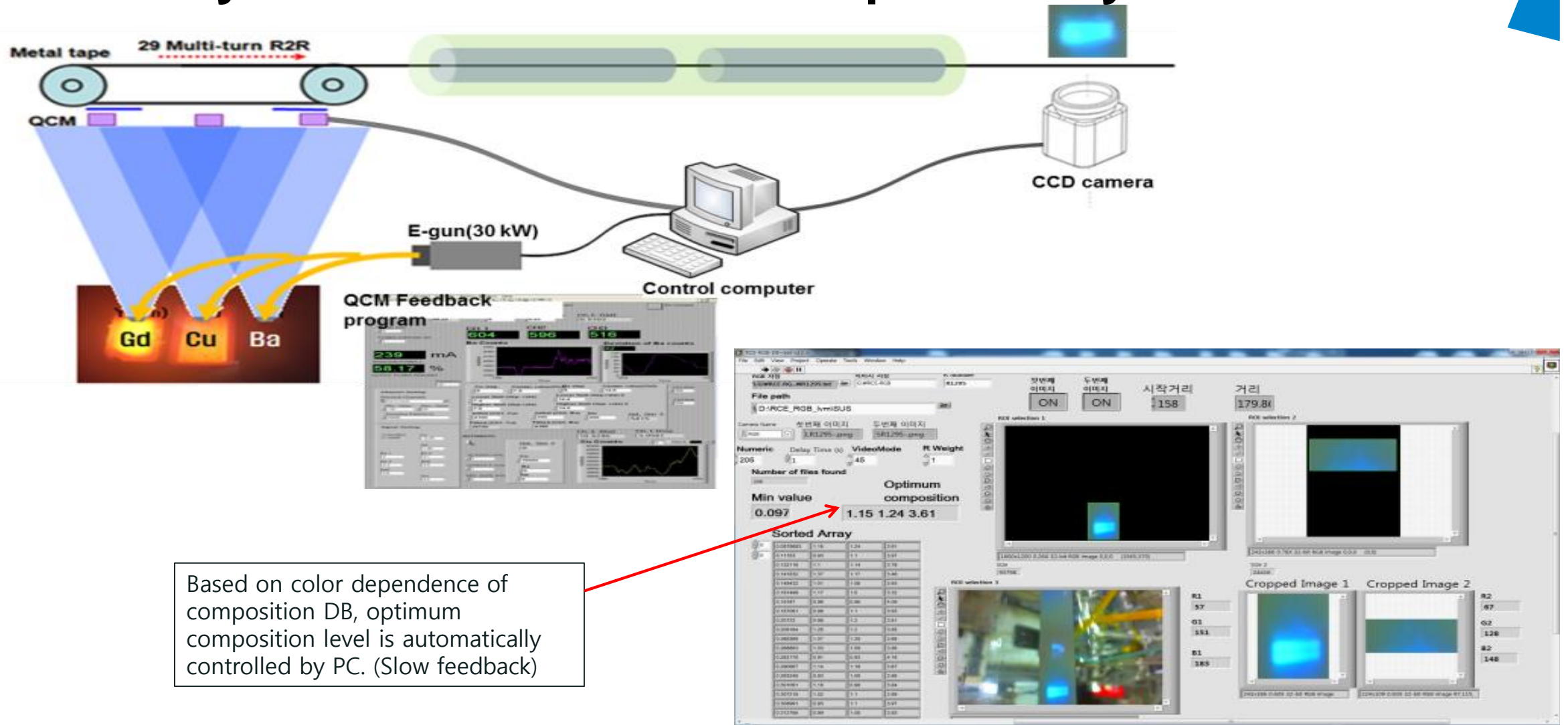


(110) spot

- Because of different evolution of $\Delta\phi$ & $\Delta\omega$, optimization is very important for high quality 2G wire.
- Intensity & tilt angle of MgO (110) spot is one of the most important parameter.



Quality Control : RCE Vision Inspection System

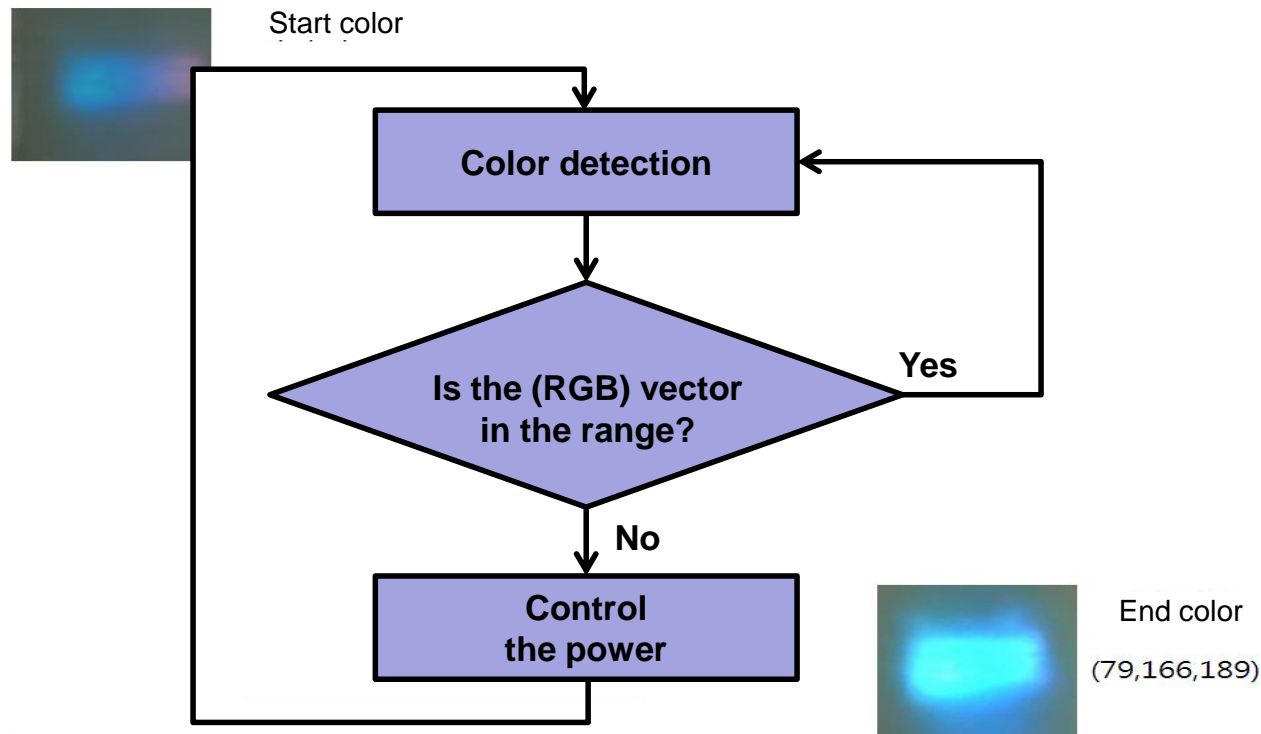


Based on color dependence of composition DB, optimum composition level is automatically controlled by PC. (Slow feedback)



Quality Control : RCE Vision Inspection System

- RCE Vision System will be introduced for increasing the uniformity of composition in RCE-DR process. The control computer takes (RGB) values in three-dimensional vector space which is transformed from the color of the tape surface.

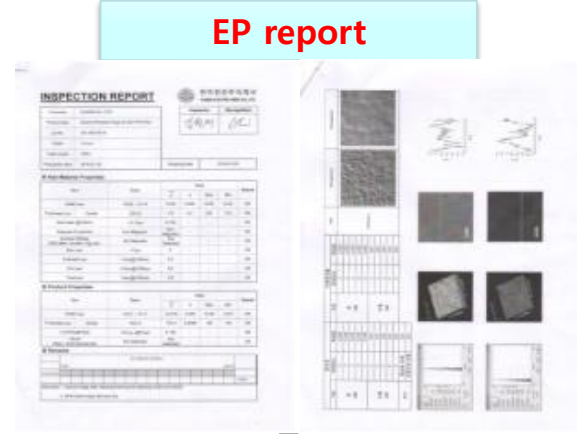
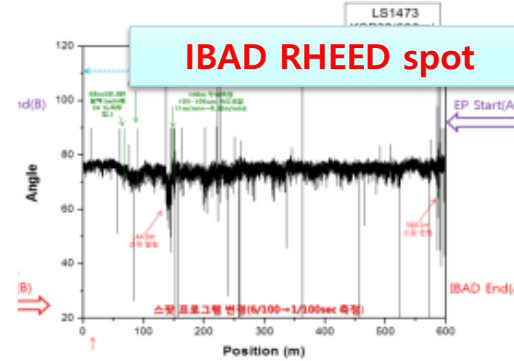
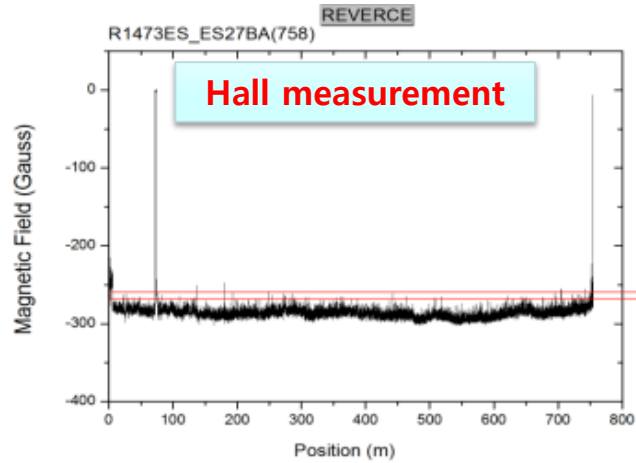


(Composition DB)

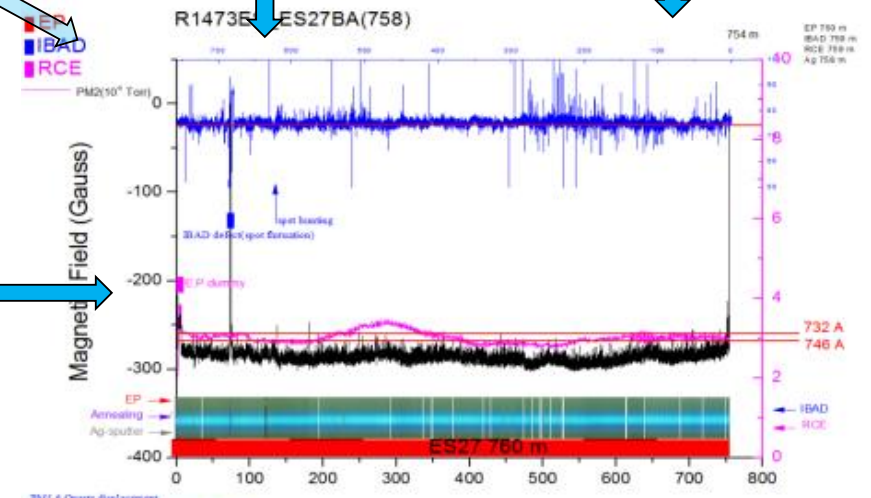




Integration of process notes & wire performance



RCE color, pressure

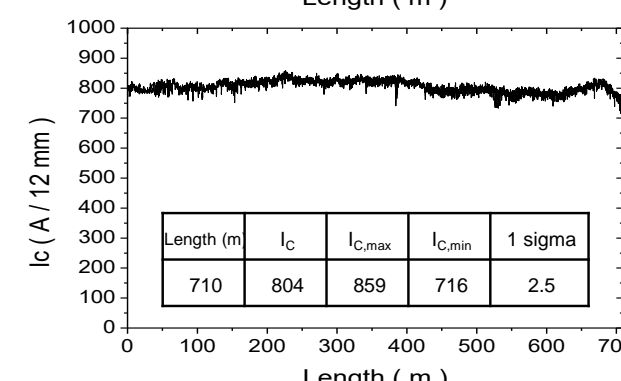
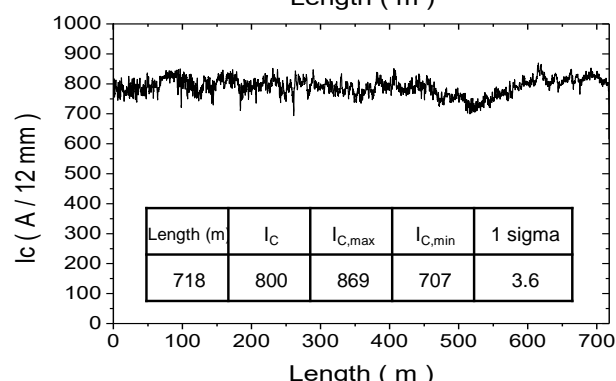
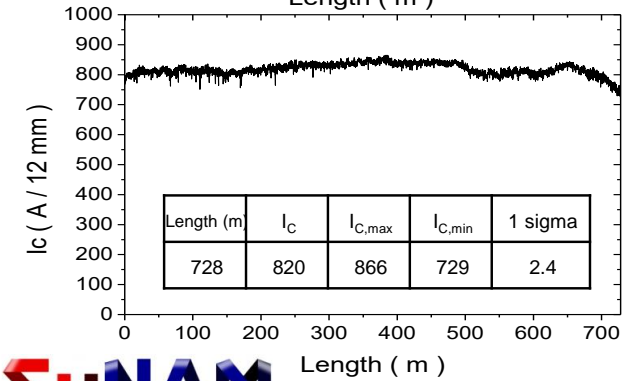
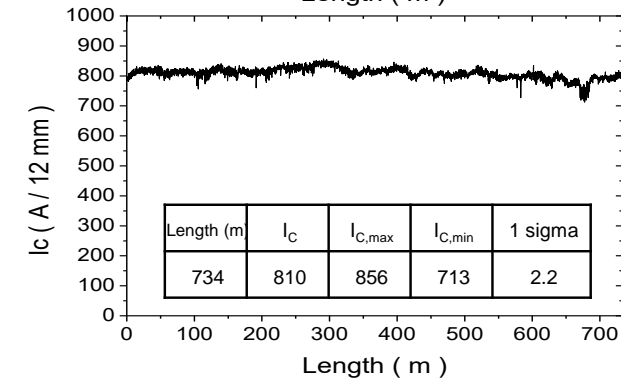
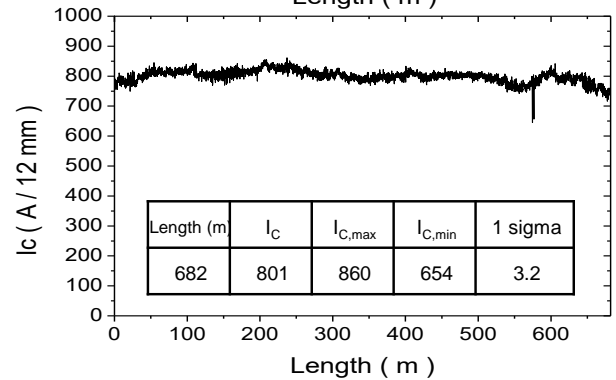
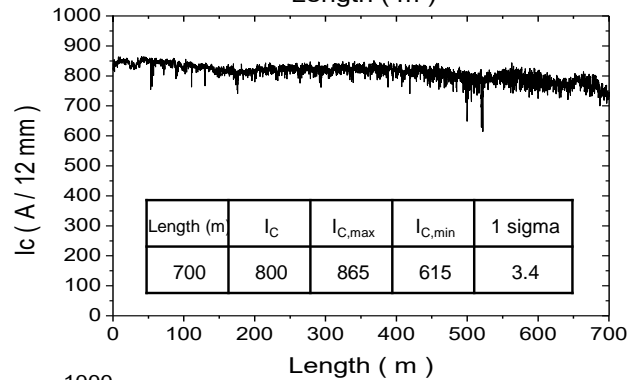
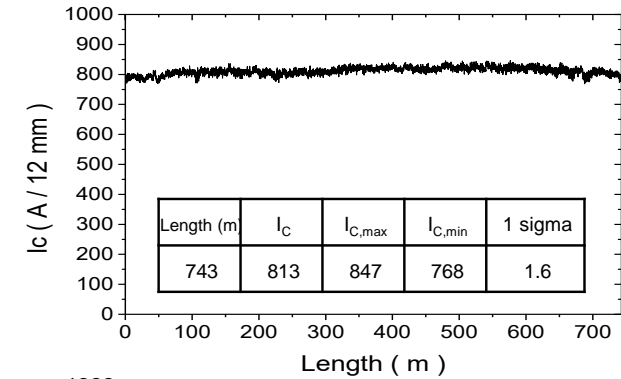
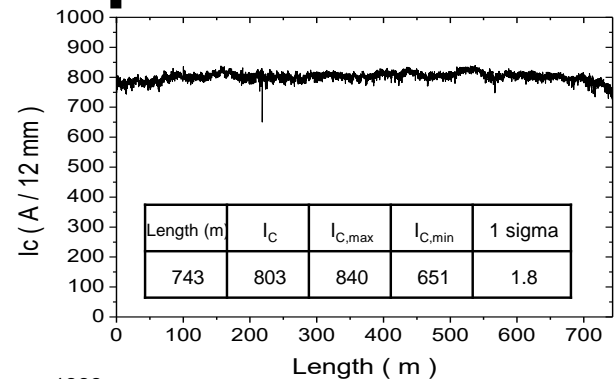
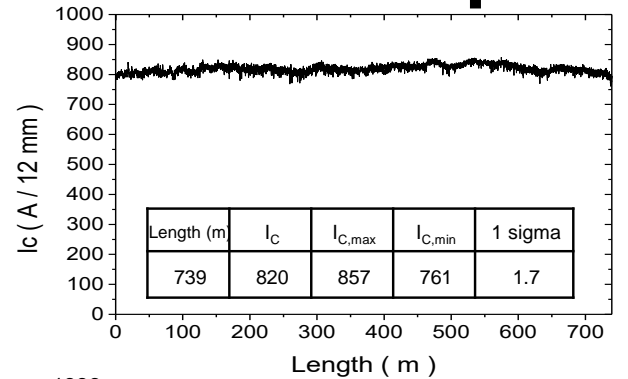


In-line control and post analysis

ES27-L1527L-R1473

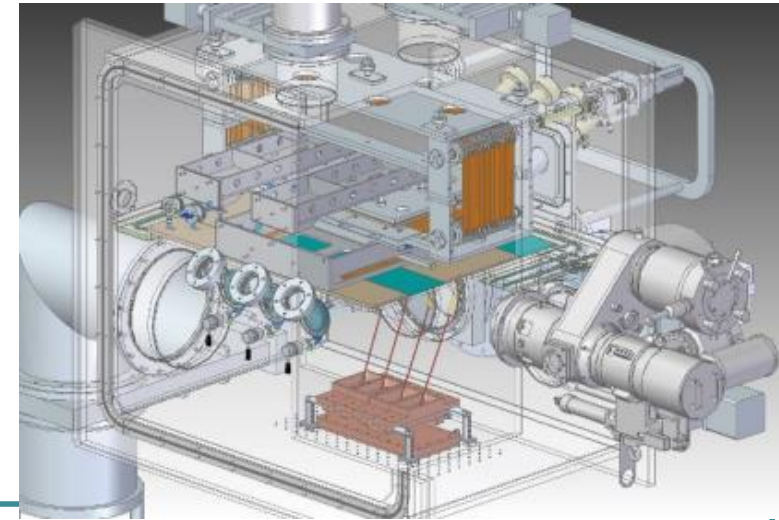
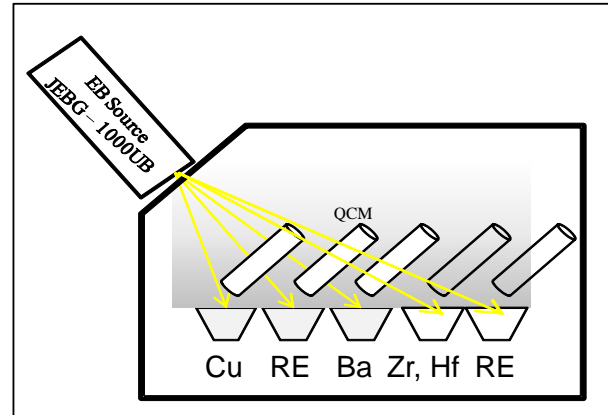


Results of process optimization of in-line control





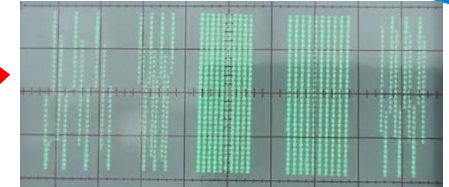
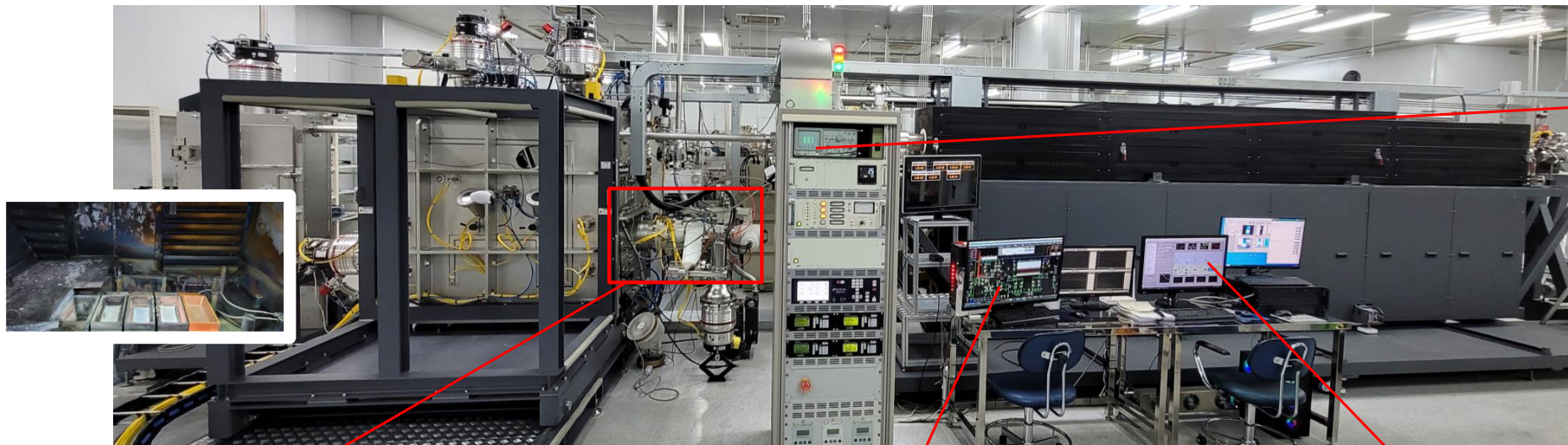
New RCE-DR system with 100 kW e-gun



- Installation of 100kW class e-gun on RCE-DR at the end of 2019.
 - As e-gun power increases,
 - various pinning materials can be deposited (Zr, Hf, Sn etc.)
 - Deposition rate can be increased (10 nm/sec → > 25 nm/sec)
 - Other rare earth materials can be deposited (Y, Y-Gd, Sm etc.)
 - Development of 40 mm ~ 120 mm-width coated conductor manufacturing process
- Y : High power e-gun is required to sweep wide areas for stable long-length process



RCE-DR system with 100kW class e-gun

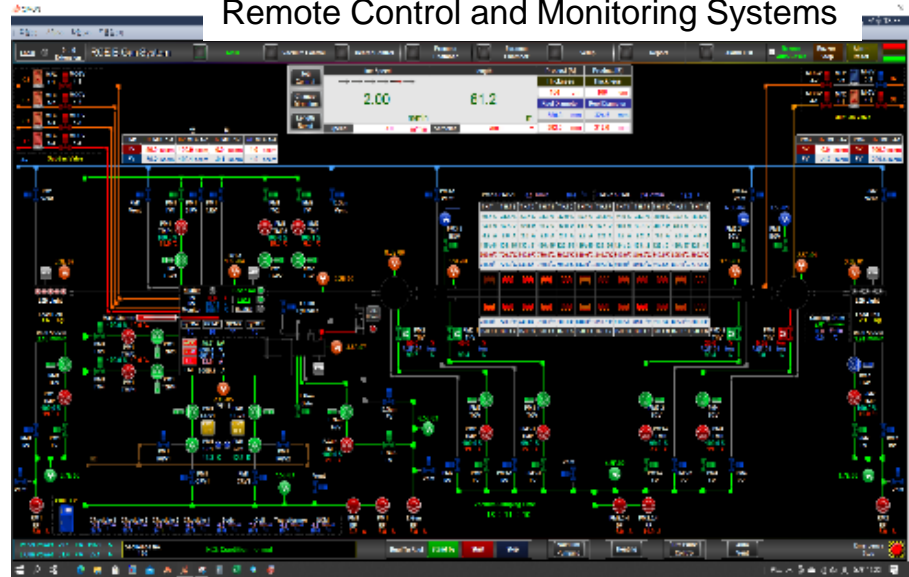


Various beam patterns can be applied to each material



100 kW class E-gun

Remote Control and Monitoring Systems

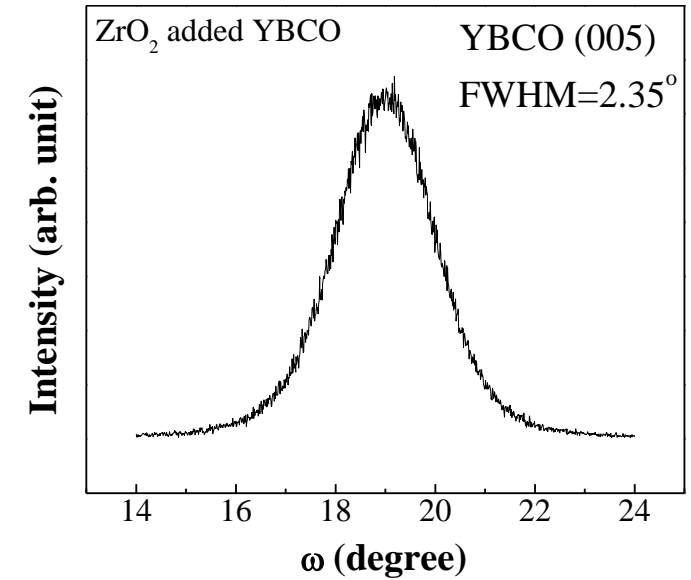
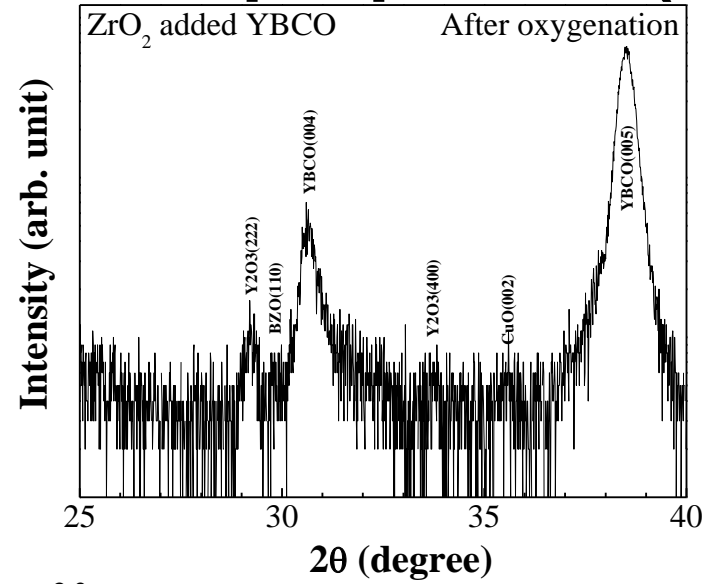
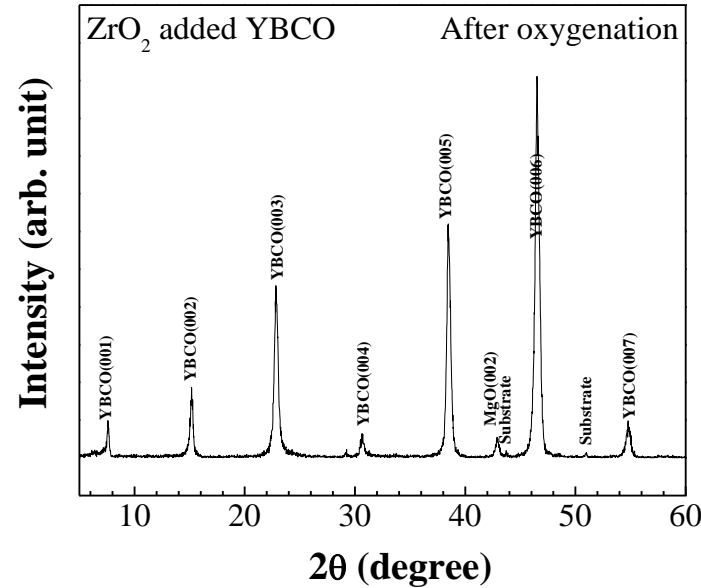


Real-time Automatic Composition Control Program

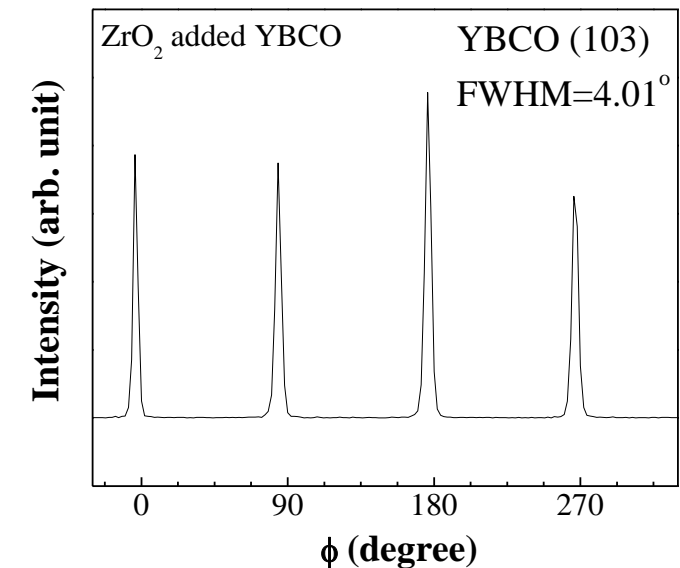
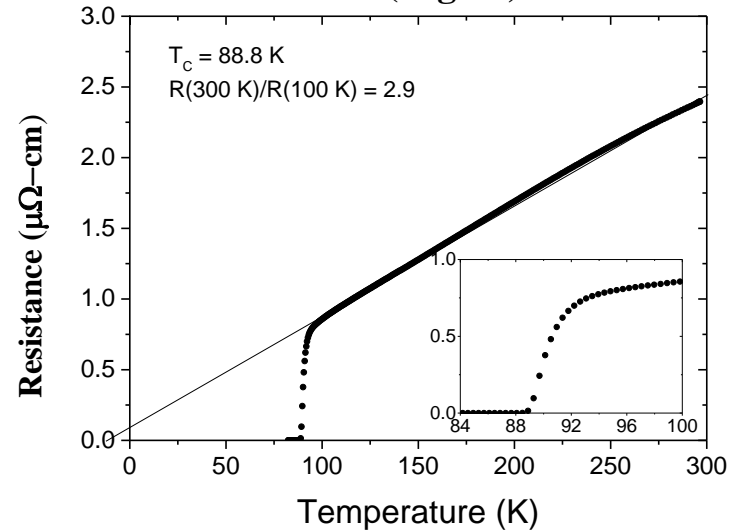




Enhancement of in-field properties (ZrO₂ co-evaporation)



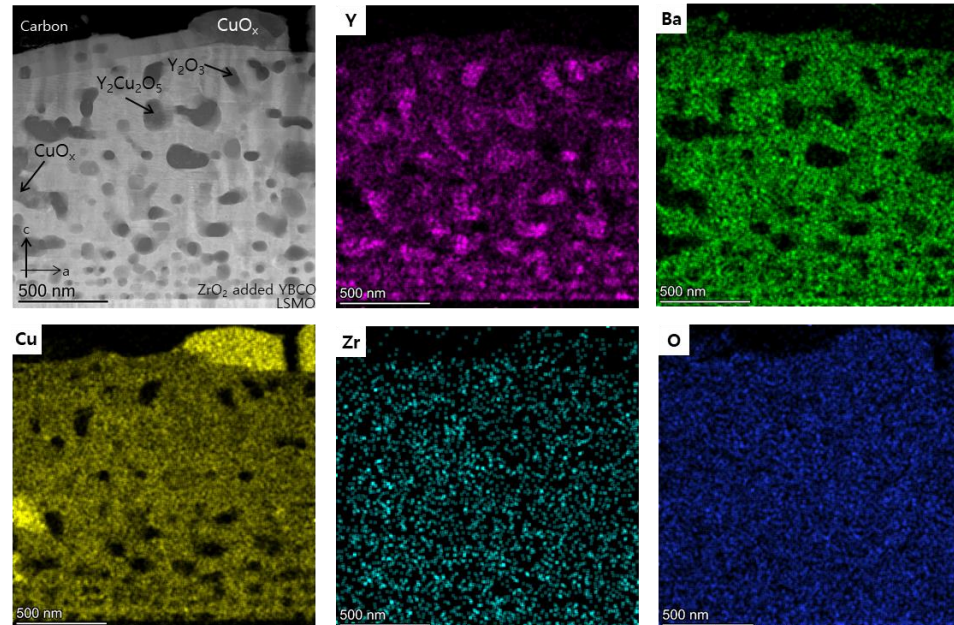
- Crystallinity by x-ray diffraction.
 - High quality YBCO even adding ZrO₂.
 - BZO randomly oriented growth.



Enhancement of magnetic properties by RCE-DR process

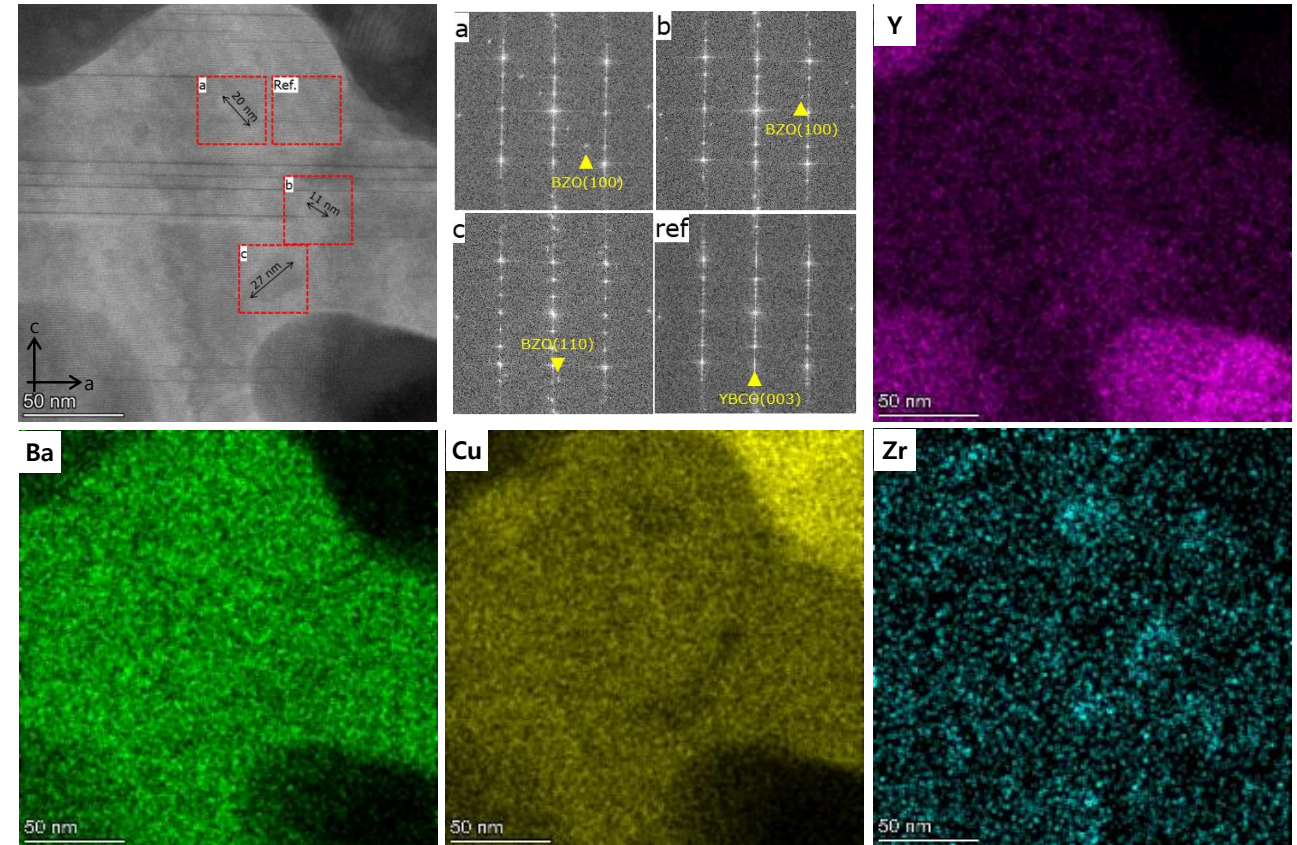
- TEM result : YBCO-ZrO₂

- Second phases are observed as self-pinning center such as Y₂O₃, CuO_x and Y₂Cu₂O₅
- Y₂O₃ particles are close to spherical, not agglomerated in YBCO
- While there are large Y₂Cu₂O₅ particles in top region, few Y₂Cu₂O₅ particles in bottom region : **optimization in progress.**



- BZO nanoparticles in YBCO

- Visible in higher magnification image
- About 10~20 nm in diameter
- Random, non-uniform distribution : **optimization in progress.**





Home-made $I_c(B, T, \theta)$ measurement set-up

- Magnet manufactured circa 2013
- Conduction-cooling, no-insulation magnet
- Brass laminated tape was used
- Field up to 4 T
- Temperature down to 15 K
- Current up to 1,000 A
- Rotating sample holder

	100 mm	200 mm
Number of DPC	22	28+2(12 mm)
Number of turns	110	133
Tape length per DPC	111 m	232 + 255 m
Total tape length	2,452 m	6,496 + 510 m



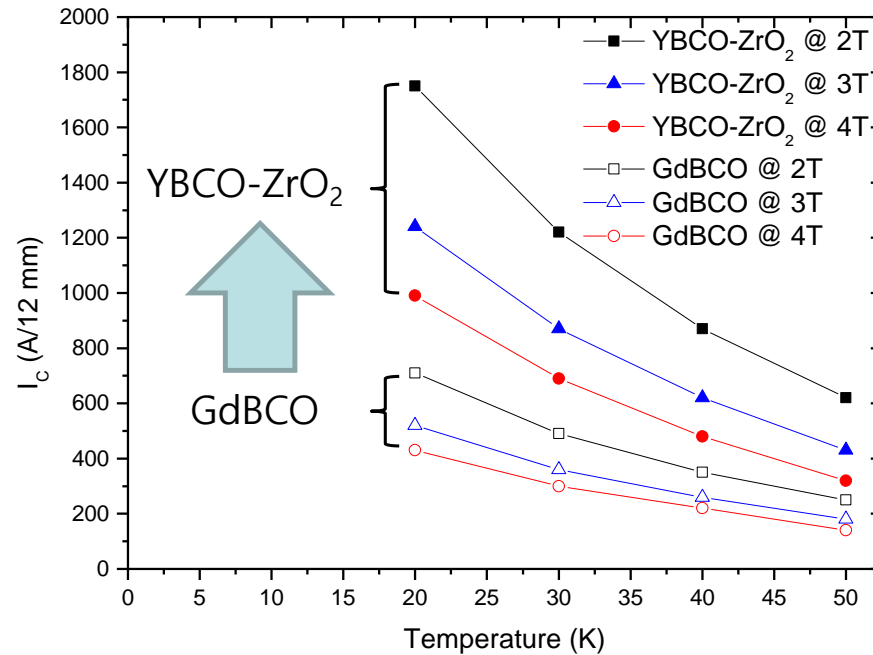
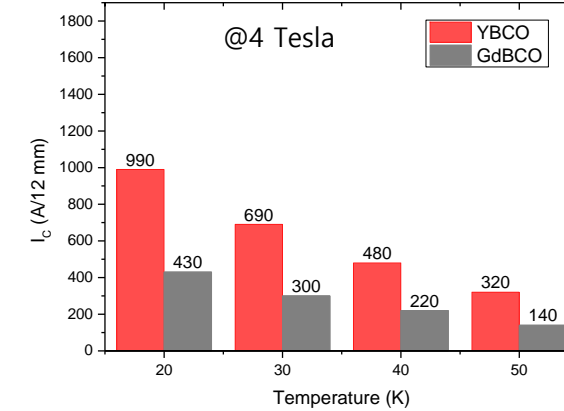
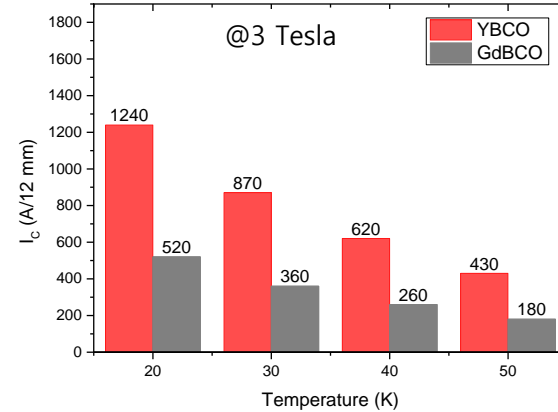
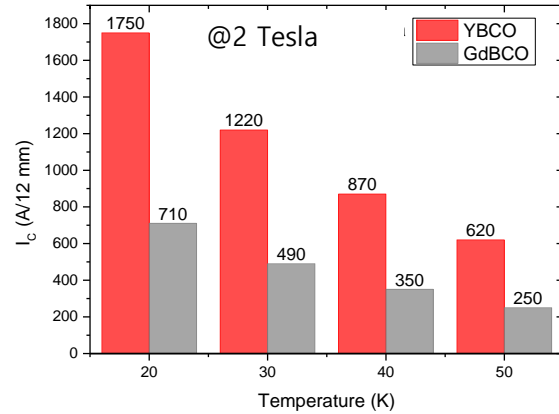
insert cryostat

203 mm RT
4T magnet

< $I_c(B-T-\theta)$ measurement system >



Enhancement of magnetic properties by RCE-DR process



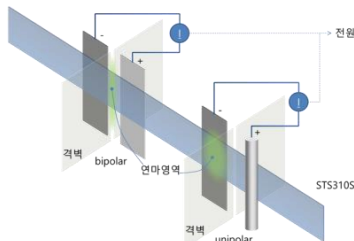
- Production and optimization of new RCE-DR with 100kW e-gun installed to improve magnetic field characteristics
- For YBCO-ZrO₂, the critical current under magnetic field increased more than twice compared to GdBCO, although 77 K, s.f. values are less than half those of GdBCO.
- Research is underway to add not only ZrO₂ but also various RE (rare earth) materials and pinning materials (Hf, Zr, etc.).

Ongoing project plan in SuNAM

**High Throughput:
2021~2025**

- Increase production speed
- Wide-width CC (>100mm)

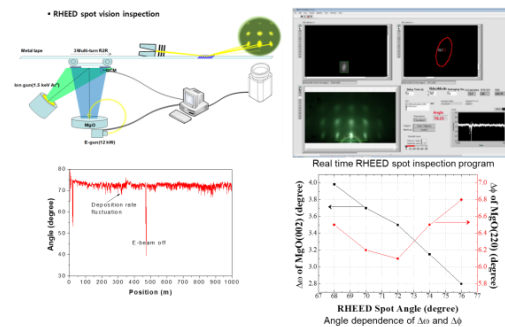
Development of wide tape electro-polishing process is complete



**Improve Yield :
2020~2021**

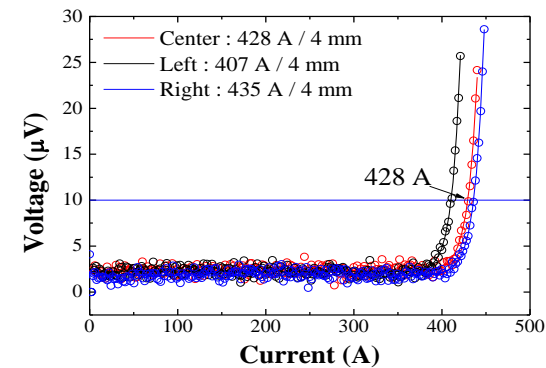
- Development of automated quality control system

Improvement for RCE-RGB feedback control with Machine Learning



**High Performance :
2020~2022**

- Improvement of magnetic properties
- Improve critical current in self field : >400A/4 mm



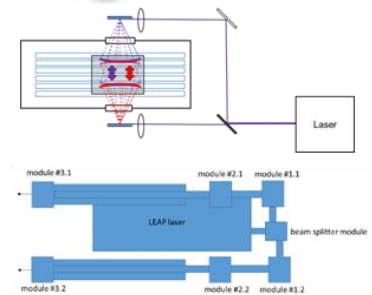
Y, Yb, Eu, Dy, Nd

Zr, Hf

Y-Yb, Zr etc.

**Apply new process
2021~2022**

- Development of PLD process
- New sputtering system



Rotary sputtering system



Summary

- SuNAM has been producing high I_c coated conductors consistently.
- We set up a new machine to evaporate pinning materials.
- We found that incorporation of BZO is possible with RCE-DR process and achieved ~2.5X enhancement at 3 Tesla, 20 K.
- Optimization for higher field property is under way.



Thanks for Attention !



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