Improvement of recovery characteristics of resistive SFCL made by GdBCO tape with several surface conditions under pressurized condition

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Introduction

➢ Background

The electric power system has been becoming more and more large-scaled and complicated because of the increase of distributed generation plants.
And the fault current will be large and the load to circuit breakers will increase.

SFCL is expected to suppress the fault current and stabilize power systems.

➢ Resistive SFCL

- Feature

Under normal operating condition
→ The impedance is very small because resistive SFCL is superconducting state.

When a fault current occurs
→Superconducting section of this SFCL turns to normal conducting state and the impedance becomes large.

- Condition for practical use

After limiting a fault current, resistive SFCL have to return to superconducting state for next operation.

The recovery time, defined as the time taken by the superconducting component to recover to the initial state (superconducting state), is important for practical use.

- Problems

The heat generated by the resistance during suppressing a fault current is large and heat transfer reaches film boiling region. It takes long time for resistive SFCL to return to normal-operating state because of the low heat flux on the superconductor surface in film boiling region.

➢ Purpose

To examine the effects of cooling fins and PTFE coating on the cooling property improvement under pressurized condition, the boiling phenomena on GdBCO tape with no fins or no coating and on the tapes with cooling fins or PTFE coating were observed by a high speed camera.

Experimental Details

➢ Apparatus

Cryostat

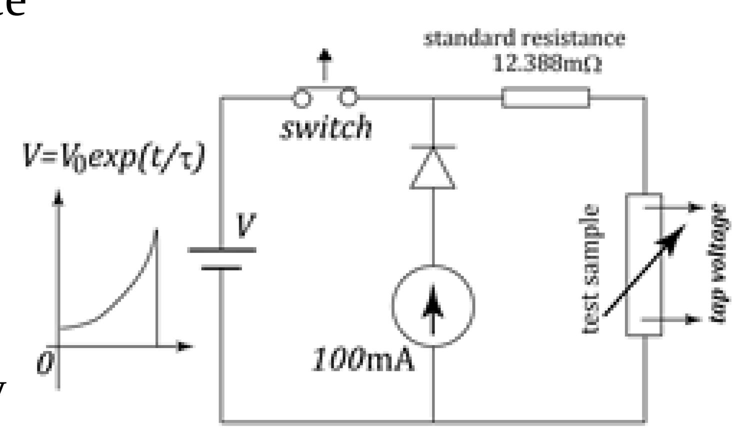
- **A pressure-proof cryostat**

→The cryostat is a double structure and has a vacuum layer for thermal insulation. The vessel can be used at most 0.6 MPa in absolute pressure. The vessel has 2 windows of which diameters are 130.8 mm

- **A high speed video camera (NAC image technology)**

→The photograph was taken by the high speed video camera with 500 frames s^{-1} from a window and LED lamp turned on to brighten the heated surface while photographing the phenomenon.

➢ Method



Test circuit

- The samples were heated over the critical current by the power source, which can apply direct current up to 600A.
- The voltage of the power source was exponentially increased as following;

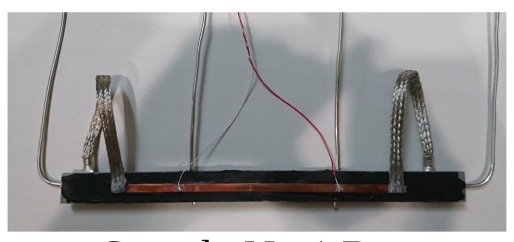
$$V = V_0 \exp(t/\tau)$$

After the voltage reached the desired value, the current was cut off and infinitesimal current of 100mA was applied in order to measure the temporal change of the electrical resistance.

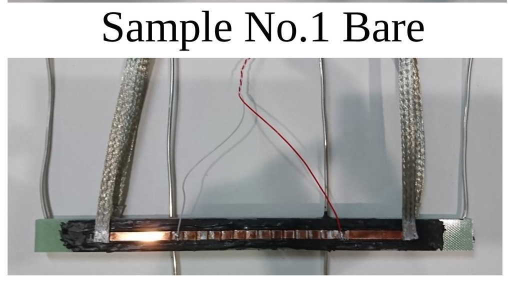
- The heat input with the period τ of 50ms and 100ms was applied to the test samples under 0.1 MPa, 0.15 MPa, 0.2 MPa, and 0.25 MPa in absolute pressure. In each case, the temperature of LN2 was from 77.3 K to 77.7 K.
- In addition, Sample No.1 was examined under 0.3 MPa, 0.35 MPa, 0.4 MPa, 0.45 MPa, and 0.5 MPa.

➢ Test Sample

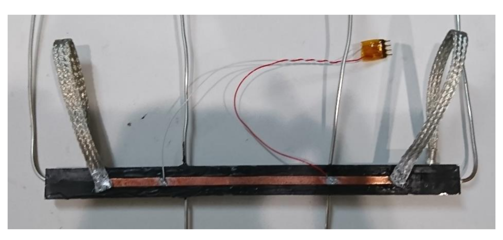
Test samples were GdBCO tapes. The length and width of the tapes are 155 mm and 4 mm respectively. The power leads and voltage taps were soldered on the sample surface apart from cooling fins.



Sample No.1 Bare



Sample No.2 L-shaped Cu fin



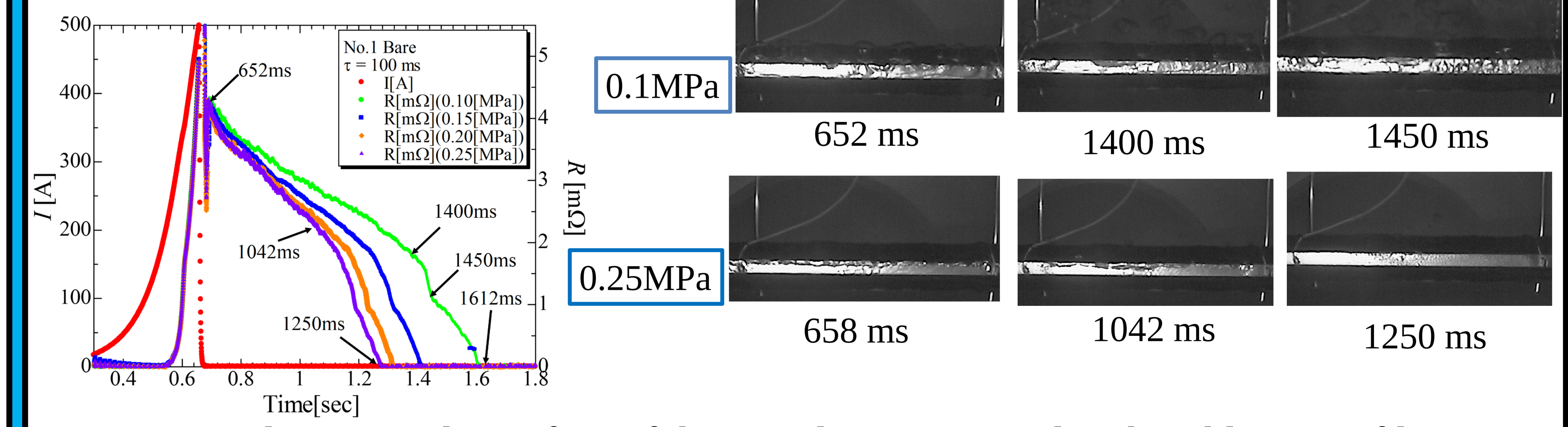
Sample No.3 PTFE

Data of Samples

No.	Surface	Tap [mm]	Ic[A]	n-value	R [mΩ] at room temperature
1	Bare	84.2	135.7~149.5	23.7	6.16
2	Cu fins	81.2	133.8~147.3	24.0	4.76
3	PTFE	84.9	135.7~149.5	23.7	6.26

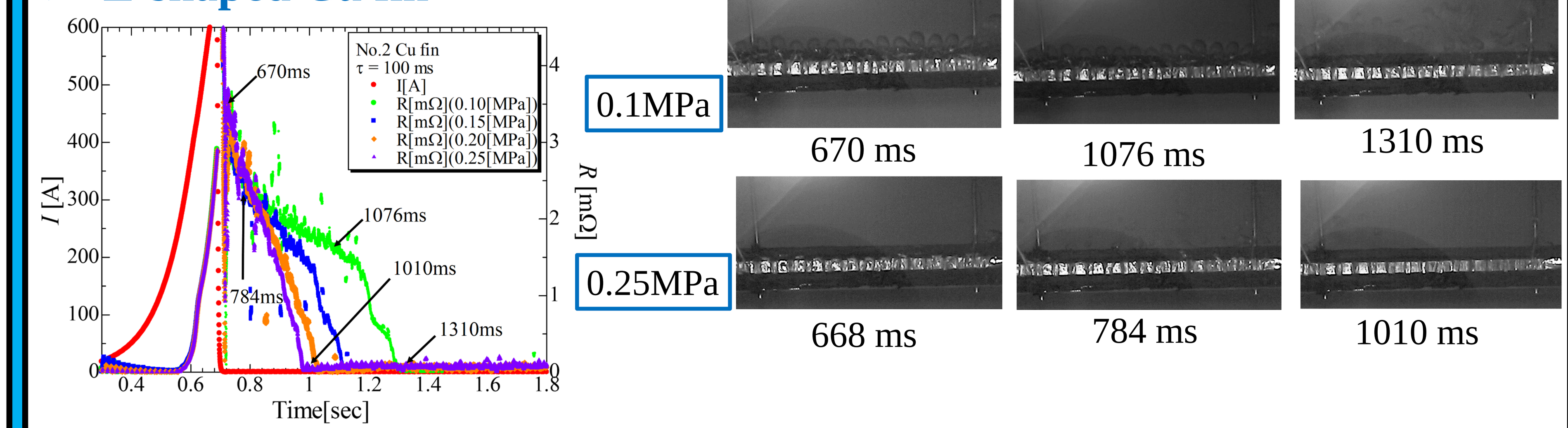
Results and Discussion

➢ Bare



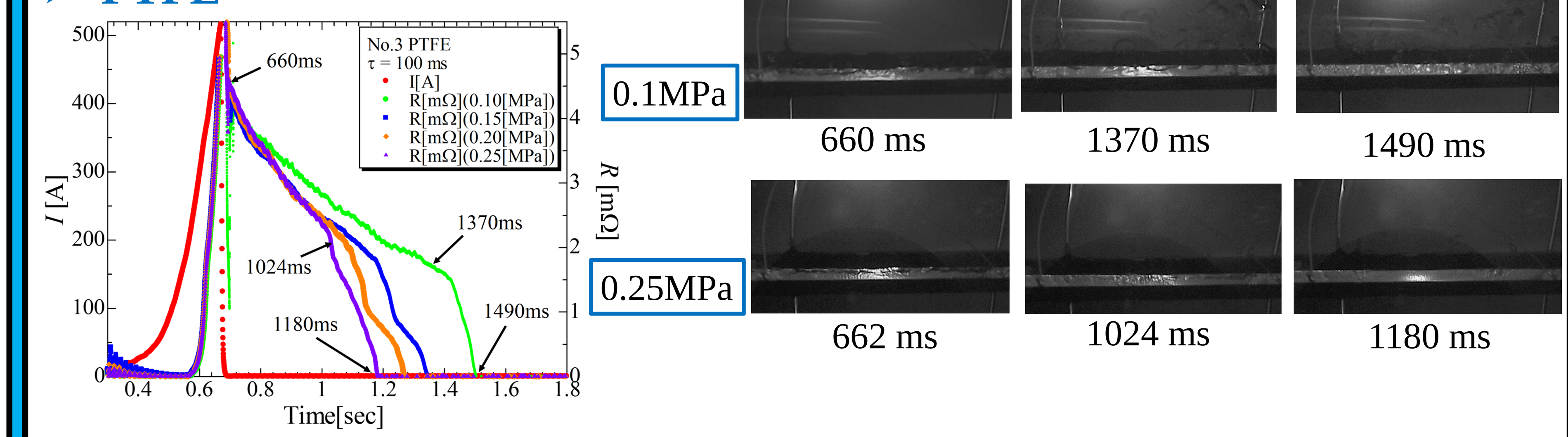
- 652ms and 658ms : The surface of the sample was covered with stable vapor film.
- 1400ms and 1042ms : The vapor film started to be broken and the nucleate boiling area was developing whole over the sample. The gradient of resistance change is steep.
- 1450ms : A part of vapor film remains on the left side of the tape and the gradient of resistance change becomes gentle.
- 1612ms and 1250ms : The vapor film vanished on the surface.
- In case of 0.25MPa, the vapor film started to be broken earlier, and the size and amount of bubbles were smaller than the case of 0.1Mpa.

➢ L-shaped Cu fin



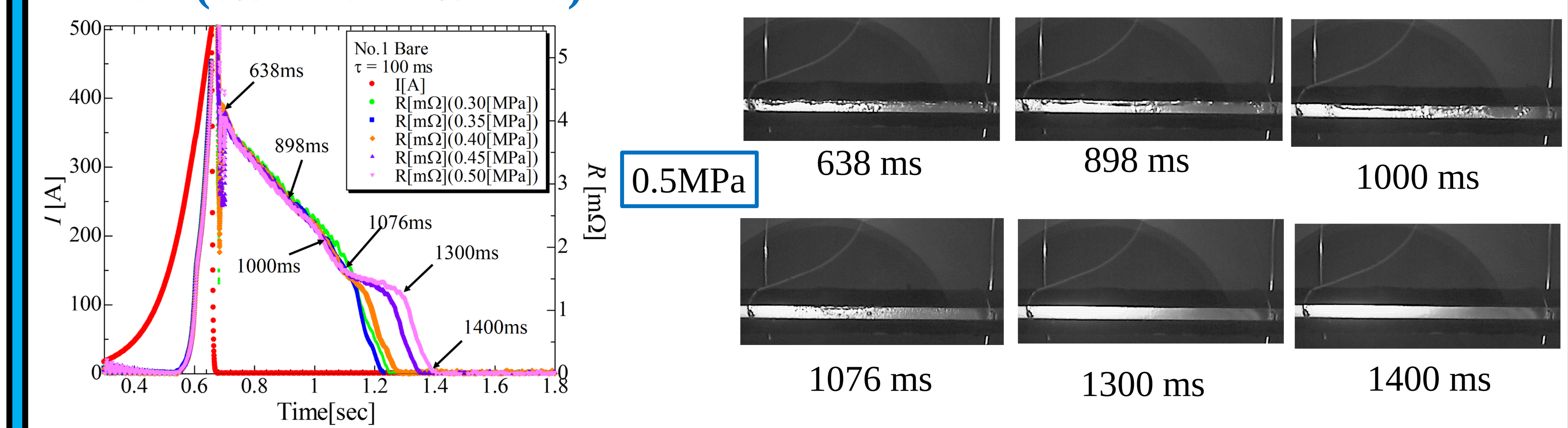
- 670ms and 668ms : The surface of the sample was covered with stable film vapors but the tips of the fins were not covered.
- 1076ms and 784ms : The transition from film boiling to nucleate boiling began from the top part of fins.
- 1310ms and 1010ms : Nucleate boiling occurred on the entire surface.
- In case of 0.25MPa, the size and amount of bubbles were smaller than the case of 0.1Mpa.Compared with the boiling phenomenon of the bare sample, there is more amount of the bubbles generated from the samples surface than that of bare sample.

➢ PTFE



- 660ms and 662ms : The vapor film was made on the surface.
- 1370ms and 1024ms : The transition from film boiling to nucleate boiling occurred.
- 1490ms and 1180ms : The area of nucleate boiling spread to the entire surface.
- There is less quantity of bubbles left from PTFE coating samples than that of the test sample with Cu fins. In case of 0.25MPa, the vapor film started to be broken early.

➢ Bare(0.3MPa～0.5MPa)



- 638ms and 898ms : The vapor film was made on the surface and remained.
- 1000ms and 1076ms : The nucleate boiling area was developing from either side.
- 1300ms : The liquid nitrogen on the surface of the tape was in non-boiling area, but the resistance remained.
- 1400ms : The sample recovered to the superconducting state.
- The recovery time extended when the pressure was beyond 0.4MPa.
- It seems that it took time to cool down to the critical temperature because the saturation temperature of nitrogen exceeded the critical temperature of Sample No.1.

Conclusion

- Application of pressure improved cooling property by preventing formation of stable vapor film regardless of surface conditions.
- On the other hand, the recovery time extended when the pressure was beyond the critical pressure at which the saturation temperature of nitrogen exceeded the critical temperature of the superconducting tape.