etching YBCO thin films into 2 mm wide lines by photolithography. They were patterned into various shapes such as meander, bi-spiral, and spiral. Fig. 1 shows the various patterns of the current limiting elements.

(a) (b) (c)

Fig. 1. The pattern shapes of current limiting elements. (a) meander, (b) bi-spiral, (c) spiral shape

Critical current densities of edge areas were usually much lower than those of other areas. The edge areas are also likely to be damaged during experimental setup. So we used only areas within 40 mm diameter on wafers as current limiting elements as shown in Fig. 1. The three patterns were designed with the same values of parameters such as a diameter, width of lines, and the gap between lines to compare the properties of three samples.

3. 결과 및 고찰

Fig. 2 shows the resistance behavior during 5 cycles after fault instant as a function of time for SFCL elements with three pattern shapes at applied voltage of 40 V_{rms}. R_{RT} in the Fig. 2 represents the resistance of the sample measured in the room temperature, and R(t) represents the resistance of the sample measured in the nitrogen bath at applied voltage of 40 V_{rms}. Resistance rise was similar right after quench instant, but the resistance after 5 cycles from quench instant was low at spiral shape. Quench was not developed completely under the applied voltage of 40 V_{rms} since transport current was low and propagation by heat generated at quench points was slow. In addition, it is reported that the cooling efficiency near electrode areas is higher than those of other areas [9]. Therefore, we speculated that the resistance value of the spiral shape was lower because the temperature of current limiting elements increased slowly due to fast cooling by the electrode near center area. Center area of SFCLs based on YBCO films usually shows higher temperature rise [9]. This may act as a disadvantage on the point of simultaneous quench which is necessary to increase voltage rating of an SFCL through the serial connections of current limiting elements. However, this problem was solved since resistance values became almost same at higher voltages as shown in Fig. 3.

Fig. 3 represents resistance normalized to the resistance at room temperature at applied voltage of 180 V_{rms}. The temperature of each samples increased up to 238 K after 5 cycles from quench instant and resistance rise behavior was almost the same. It was proved by our experiments that current limiting elements could be operated safely against degradation and aging up to 250 K [6]. So, we did not increase the applied voltage any further. We found that the temperature rise behavior was similar, since quench was completed at this voltage and since generated heat was mainly propagated through the substrate afterwards [4]. In other words, the quench characteristics of three pattern shapes were similar at maximum applied voltage.

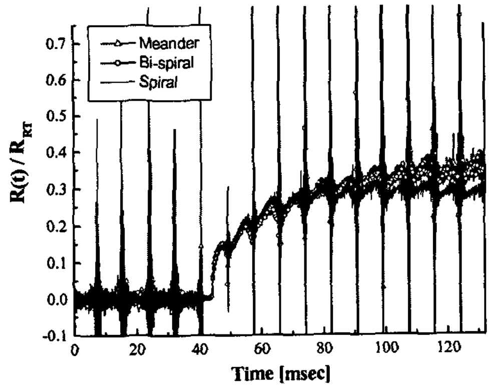

Fig. 2. The resistance normalized to the room temperature resistance of three pattern shapes as a function of time (applied voltage : 40 V_{rms}, fault angle : 0).

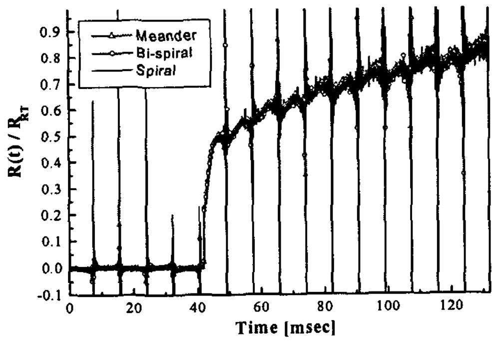

Fig. 3. The resistance normalized to the room temperature resistance of three pattern shapes as a function of time (applied voltage : 180 V_{rms}, fault angle : 0).

4. 결 론

Three pattern shapes have been designed, constructed, and tested to determine optimal shape of current limiting elements for their power applications. They are meander, bi-spiral and spiral shapes. They were designed with the same values of parameters such as diameter, width of lines, and the gap between lines to compare the properties of three samples. YBCO thin films with two-inch diameter were used for construction of these shapes. Resistance rise behavior of these pattern shapes at maximum applied voltage was almost same. That is, quench behavior of three pattern shapes was similar. Finally, we investigated maximum voltage drop between current limiting lines at applied voltage of 180 V_{rms}. The highest voltage occurred at bi-spiral shape as 158.4 V_{rms} while voltage of 44.9 V_{rms} occurred at meander shape. This makes it possible to lower the insulation level at the same applied voltage in case of SFCLs with the meander shape. We concluded the meander shape was appropriate as a pattern shape to design a resistive SFCL using YBCO films except the concentration of electric field. However, further research is still needed to design optimal shape in terms of electromagnetic behavior, local heating properties, and AC loss, etc.

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참고 문헌

[1] T. Hoshino, K. M. Salim, M. Nishikawa, I. Muta and T. Nakamura, "DC reactor effect on bridge type superconducting fault current limiter during load increasing", IEEE Trans. on Appl. Supercon., Vol. 11, No. 1, p. 1944, 2001.

[2] H. Shimizu, K. Kato, Y. Yokomizu, T. Matsumura and N. Murayama, "Resistance rise in Bi2223 superconducting bulk after normal transition due to overcurrent", IEEE Trans. on Appl. Supercon., Vol. 11, No. 1, p. 1948, 2001.

[3] M. Noe, K. P. Juengst, F. Werfel, L. Cowey, A. Wolf and S. Elschner, "Investigation of

high-Tc bulk material for its use in resistive superconducting fault current limiters", IEEE Trans. on Appl. Supercon., Vol. 11, No. 1, p. 1960, 2001.
[4] A. Heinrich, R.Semerad, H. Kinder, H. Mosebach, and M. Lindmayer, "Fault current limiting properties of YBCO-films on sapphire substrates", IEEE Trans. on Appl. Supercon., Vol. 9, No. 2, p. 660, 1999.
[5] K. Tekletsadik and M. Saravolac, "Development of a 7.5 MVA superconducting fault current limiter", IEEE Trans. on Appl. Supercon., Vol. 9, No. 2, p. 672, 1999.
[6] H. S. Choi, H. R. Kim, O. B. Hyun and S. J. Kim, "Quench properties of Y-Ba-Cu-O films after overpowering quenches", IEEE Trans. on Appl. Supercon., Vol. 11, No. 1, p. 2418, 2001.
[7] H. R. Kim, H. S. Choi, H. R. Lim, I. S. Kim and O. B. Hyun, "Initial quench development in uniform Au/Y-Ba-Cu-O thin films", IEEE Trans. on Appl. Supercon., Vol. 9, No. 2, p. 2414, 2001.
[8] H. S. Choi, H. R. Kim and O. B. Hyun, "Operating properties of superconducting fault current limiters based on YBCO thin films", Cryogenics, 2001. Vol. 41, No. 3, p. 163, 2001.
[9] H. R. Kim, H. S. Choi, H. R. Lim, I. S. Kim and O. B. Hyun, "Quench distribution in superconducting fault current limiters at various voltages", Cryogenics, 2001. Vol. 41, No. 4, p. 275, 2001.
[10] H. S. Choi, O. B. Hyun, and H. R. Kim, "Quench characteristics of resistive superconducting fault current limiters based on YBCO films", Physica C, Vol. 351, No. 4, p. 415, 2001.
[11] H. S. Choi, O. B. Hyun, H. R. Kim and S. D. Hwang, "Characteristics of 15 kVA superconducting fault current limiters using thin films", J. of KIEEME(in Korean), Vol. 13, No. 12, p. 1058, 2000.
[12] H. R. Kim, O. B. Hyun, H. S. Choi, S. D. Hwang and S. J. Kim, "Quench propagation in resistive SFCL", J. of KIEEME(in Korean), Vol. 13, No. 4, p. 337, 2000.
[13] H. S. Choi, S. D. Hwang and O. B. Hyun, "Current limiting characteristics of a resistive SFCL for a single-line-to-grounf fault in the 22.9 kV system", J. of KIEEME(in Korean), Vol. 14, No. 6, p. 505, 2001.