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Improvement of power-handling capability of superconducting filters using 3D-matrix microstrip lines

S. Ohshima, S. Takahashi, M. Endo, and A. Saito
Graduate School of Science and Engineering, Yamagata University
4-3-16, Jonan Yonezawa, 992-8510, Japan
E-mail: ohshima@yz.yamagata-u.ac.jp

Abstract. We examined power-handling capability of superconducting filters using three different types of resonator: type one, a conventional microstrip line, type two, a layered-film microstrip line, and type three, a 3D-matrix microstrip line. The 3D-matrix microstrip line was made by dividing a type two microstrip line into narrow lines. We used NbN thin films as superconducting microstrip lines. The optimal shape of the filters was designed by using a Sonnet electromagnetic simulator, and the power-handling capability of these filters was measured at 6.5 K. The values of a conventional microstrip line, a layered-film microstrip line, and a 3D-matrix microstrip line filters were 21.2, 22.9, and 24.6 dBm, respectively.

1. Introduction

Superconducting bandpass filters (SBFs) have advantages such as a high frequency selection, small insertion loss, and a large out-of-band rejection. Consequently, such filters have been put to practical use in receiving systems of base stations for wireless communications in the U.S.A and China. SBFs have only been used in receiving systems in which small amounts of electric power flow. If the power-handling capability of the SBFs can be improved, it could be used as a transmitting filter, and hence its range of use could be expanded. Wide microstrip line resonator filters [1-3] and the patch resonator filters [4, 5] have been reported to increase power-handling capability. Filters with power-handling capability over one watt can be obtained; however, they are not useful for designing multi-resonator filters. This problem may be overcome if we can design filters by using microstrip lines with high power-handling capability. We think that the limit of power-handling capability of filters is caused by the current concentration at the outer edge of a microstrip line. Therefore, it is very important to reduce the current concentration to increase power-handling capability of SBFs.

With this goal in mind, we have proposed some resonator shapes to reduce the current concentration at the outer edge of a microstrip line in previous papers [6-11]. The sliced microstrip line filters and layered-film microstrip line filters could increase the power-handling capability of the filter compared with a conventional microstrip line filter.

In this paper, we present a new microstrip line shape (3D matrix microstrip line) to reduce the current concentration at the outer edge of a microstrip line. The 3D microstrip line was constructed by dividing it into a narrow line of a layered film microstrip line. The narrow line consists of alternately stacked superconducting thin film (NbN) and dielectric thin film (AlN) layers on an MgO substrate. We describe how the power-handling capability of SBFs was improved experimentally using the 3D matrix resonators.

2. Experimental Procedure

2.1. Filter design

We designed a three-pole Chebyshev type bandpass filter based on the following specifications; a center frequency of 5.0 GHz, band width of 100 MHz, and pass-band ripple of 0.01 dB. The frequency response of the SBFs was simulated using an electric magnetic simulator (Sonnet EM). It is difficult to simulate the shape of 3D-matrix microstrip line SBFs using Sonnet EM, and therefore we used the fact that the shape of the 3D-matrix microstrip lines was the same as that of the layered-film microstrip line. The sliced number for 3D-matrix microstrip line was thirteen. Figure 1 shows schematic drawings of the conventional microstrip line filter (Fig.1(a)) and 3D-matrix microstrip line filter (Fig.1(b)) and the simulation results of frequency response. S_{11} of these filters was less than -30 dB, and the in-band ripple of these filters was less than 0.02 dB.

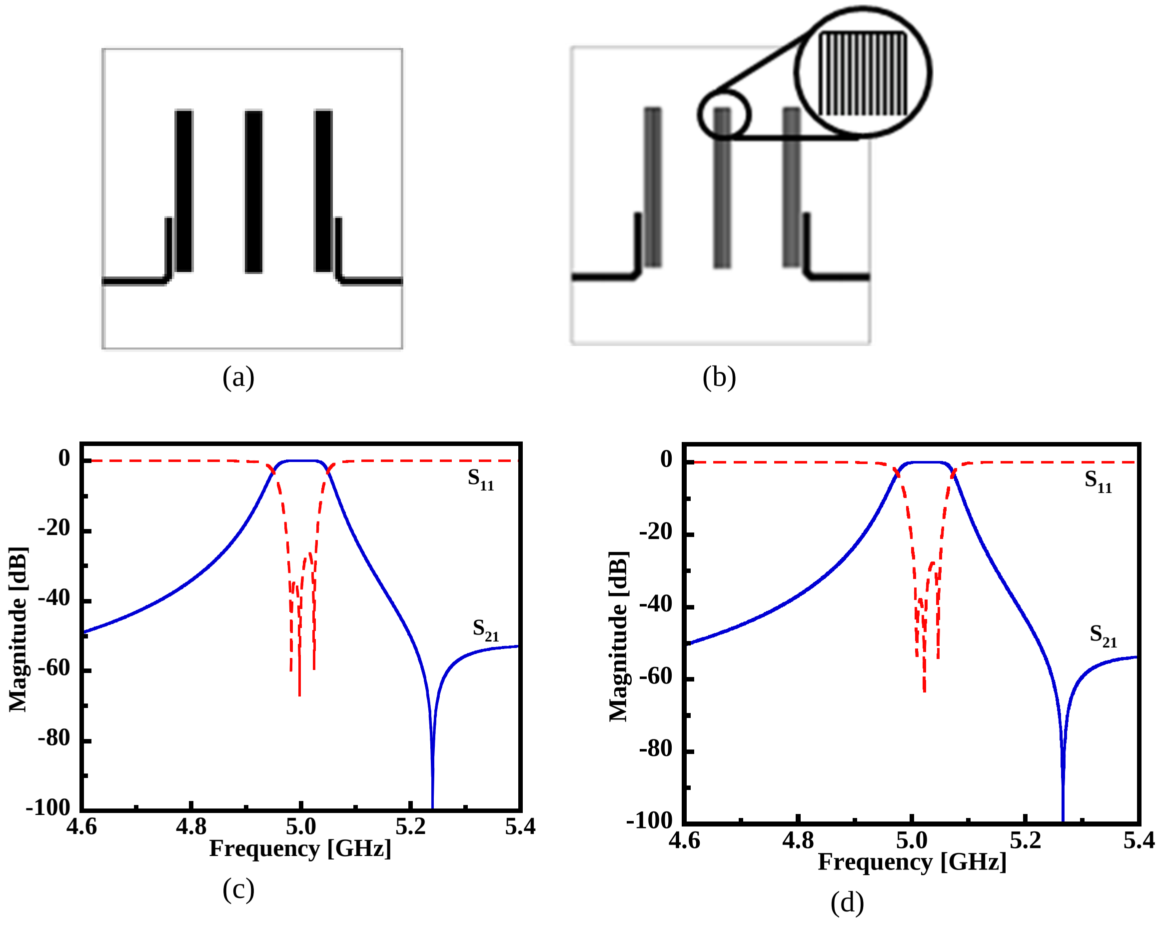

Fig.1. Schematic drawing of filter shapes and simulation results of frequency responses of the filters. (a) Shape of a three-pole conventional filter; (b) Shape of a three-pole 3D-matrix filter; (c) simulation results for a conventional filter; (d) simulation results for 3D-matrix filter.

2.2 Fabrication of the 3D-matrix microstrip line filter

We prepared NbN single-sided 600-nm thick film and NbN/AlN/NbN single-sided 300/20/300 nm multi-layered film on MgO substrate by dc magnetron sputtering. The schematic drawings of the films are shown in Fig.2. The Tc of these films was about 14 K, and their surface resistance was about 0.2 mΩ at 21.8 GHz below 7 K, which was the same as that of high quality YBCO thin films at 7 K. These characteristics were reported in a previous paper [6]. The grain orientation of NbN was

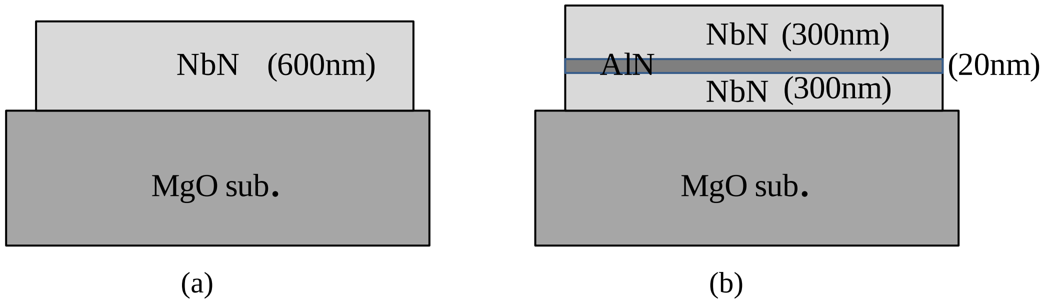

Fig.2. Schematic drawing of NbN mono-layered film and NbN/AlN/NbN multi-layered film on MgO substrate.

measured by X-ray ϕ-scan diffraction. We found that NbN and NbN/AlN/NbN showed hetero-epitaxial growth on the MgO substrate. We fabricated a three-pole filter using NbN and NbN/AlN/NbN thin films by conventional photolithography and ECR dry-etching techniques. We examined three differently shaped resonator filters: type one, a conventional microstrip line, type two, a layered-film microstrip line, and type three, a 3D-matrix microstrip line. Type one was made of mono-layered NbN thin film (shown in Fig.2 (a)), and types two and three were made of multi-layered thin film (shown in Fig.2(b)). The 3D-matrix microstrip line was obtained by dividing the layered-film microstrip line into narrow lines. The number of slits was thirteen.

3. Results and Discussion

Figure 3 shows the effective input power dependence on the output power in the filters made of conventional, layered-film, and 3D-matrix microstrip lines. The effective input power means the input power minus the reflected power. The vertical axis shows P_{in}- P_{out}, which is the calculated value of the input power minus the output power. If the filter has thermal loss, P_{in}- P_{out} becomes negative. We define the power proof of the filters as the value at which P_{in}- P_{out} is -0.5 dBm (dashed line in the figure). As shown in Fig.3, the electric power proofs of the conventional microstrip line filter, the layered-film microstrip line filter, and 3D-matrix microstrip line filter were 21.2, 22.9, and 24.6 dBm,

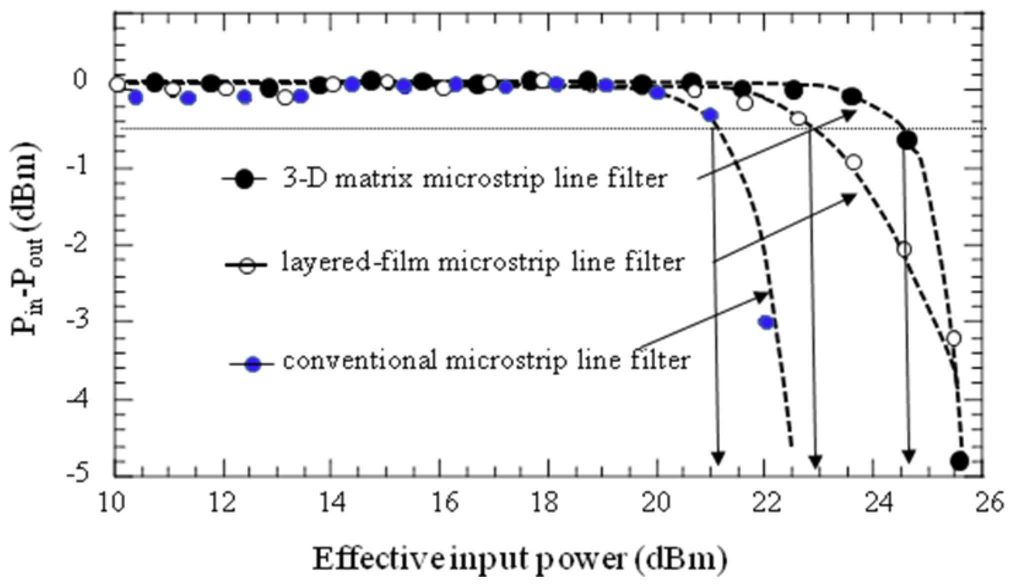

Fig.3. Effective input power dependence on P_{in}-P_{out} of the filters.

respectively. The electric power proof of the 3D-matrix microstrip line filter was larger than those of the conventional filter and layered-film filter by about 3.4 and 1.7dBm, respectively. From the simulation of the current concentration of the microstrip line, we can estimate the increase in the power proof of the filter. We reported the concentrated current of the conventional microstrip line, a sliced microstrip line, and a layered-film microstrip line [5]. The concentrated current of the conventional microstrip line is about two times larger than that of the layered-film microstrip line and 1.33 times larger than that of the sliced microstrip line. Therefore, we can estimate the difference in the power proof among these filters. The power proof of the 3D-matrix microstrip line filter may be larger than that of the conventional microstrip line filter and layered-film microstrip line filter by about 5.7 dB and about 2.9dB, respectively. The experimental results for the power proof were about 60 % of the simulation results. The estimated power proof can be realized by the optimal thickness of the microstrip line, and therefore, we must determine the optimal thickness of the superconducting and insulator films. We will be able to obtain a larger power proof with the 3D-matrix microstrip line filter.

4. Conclusion
Superconducting bandpass filters using a 3D-matrix microstrip line were designed and fabricated. The power- handling capability of the 3D-matrix microstrip line filters was 1.7 dB larger than that of a layered-film microstrip line filter and 3.4 dB larger than that of a conventional microstrip line filter. This different in the power proof occurred due to the current concentration of a microstrip line at the outer edge of a microstrip line. We clarified that 3D-matrix microstrip line was useful to increase the power proof of the microstrip line.

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