

# 國防科技學術合作協調小組研究計畫成果報告

高溫超導微波被動元件之 Ka-band 濾波器及共振器研製

Fabrication of Ka-band Filters and Resonators Using Passively High Temperature Superconducting Microwave Devices

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**國防科技學術合作協調小組研究計畫摘要表**

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| 計 劃 名 稱                                                                                                                                                                                                                                                                                                                  | 中文：高溫超導微波被動元件之 Ka-band 濾波器及共振器研製                                                                                                                                                                                                                              |       |        |                        |           |  |
|                                                                                                                                                                                                                                                                                                                          | 英文：Fabrication of Ka-band Filters and Resonators Using Passively High Temperature Superconducting Microwave Devices                                                                                                                                           |       |        |                        |           |  |
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| 計 畫 時 程                                                                                                                                                                                                                                                                                                                  | 自 91 01 01 起                                                                                                                                                                                                                                                  |       | 計畫編號   | NSC 91-2623-7-009-008- |           |  |
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| 計 劃 歸 屬                                                                                                                                                                                                                                                                                                                  | <input type="checkbox"/> 材料與應用化學 <input type="checkbox"/> (V) 電子與資訊系統 <input type="checkbox"/> 系統管理 <input type="checkbox"/> 遙 測<br><input type="checkbox"/> 航空技術 <input type="checkbox"/> 機械製作與應力 <input type="checkbox"/> 兵器系統 <input type="checkbox"/> 其 他 |       |        |                        |           |  |
| 研究內容摘要：<br><br><p>本實驗室研發以雷射蒸鍍法製作高品質雙面鈮鉕銅氧 (YBCO) 薄膜，輔以多年高溫超導微波元件製作之研發經驗，將雙面 YBCO 薄膜設計為六級的髮夾梳形帶通濾波器(hairpin-comb filter)。量測的結果顯示，樣品之中心頻率在 8.25GHz，比例帶寬為 3%，通帶的插入損耗為 0.5 dB。由於此優良之濾波器的成功製作，將有助於更複雜微波器件之研究與設計。</p>                                                                                                          |                                                                                                                                                                                                                                                               |       |        |                        |           |  |
| 學術或技術上之貢獻：（包括民間工業應用之可能性、發表論文、申請專利）<br>發表論文：<br>H. K. Zeng, T. Y. Cheng, Andy Hsiao, S. W. Wu, Y. R. Chen, L. S. Lai, J. Y. Juang, J. Y. Lin, K. H. Wu, T. M. Uen, Y. S. Gou, and H. C. Li, R. L. Wang, "Fabrication of YBCO 6-pole microstrip hairpin-type filters at 8.25 GHz", submitted to Technical Report of IEICE. |                                                                                                                                                                                                                                                               |       |        |                        |           |  |

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## 1. INTRODUCTION

The fast growth of the mobile communication industry has created a significant opportunity for implementing high temperature superconducting (HTS) technology. The HTS base subsystem composed of devices have low noise, and other superior characteristics, which promises to bring dramatic improvements for mobile communications [1, 2]. One of the first practical applications of HTS is in the area of microwave passive devices [3-12], such as filters, multiplexers, receivers, delay lines, couplers, and antennas. They all offer significant size and weight advantages combined with improved performance. For this purpose, these devices are typically constructed with various forms of coupled microstrip resonators. Among them, the parallel-plate resonators are very convenient and useful for investigating the fundamental physical parameters of the HTS films. In this case, high quality factor  $Q$  is essential and is usually achieved by using superconducting film as ground plane. This, however, has inevitably complicated both in the fabrication and measurement processes. Moreover, the advantages mentioned above can only occur when HTS devices are integrated with other microwave passive components on the same substrate. Thus, size reduction has been an important issue and offsets to establish an adequate coupling combination among the devices [11, 12].

In this report, we describe the design, fabrication, and tests of 6-pole microstrip hairpin-type band-pass filters consisted of high- $Q$  U-shape resonators [10-14]. The HTS thin films are deposited on a low-loss dielectric substrate and are processed using standard photolithography and wet etching techniques. The most widely used substrate is lanthanum aluminates ( $\text{LaAlO}_3$ ) with a dielectric constant of 25 and a loss tangent of  $\tan\delta = 6 \times 10^{-5}$  at 77 K. One challenge with the  $\text{LaAlO}_3$  substrate is that its crystal structure exhibits twining, which makes the substrate effectively inhomogeneous. This may affect the ability to set the frequency correctly in applications.

## 2. EXPERIMENTAL

Microwave components require that the HTS films be deposited onto a low loss substrate. The high quality double side  $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$  (YBCO) thin film deposited on both sides of a  $10 \times 10 \text{ mm}^2$   $\text{LaAlO}_3$  substrate was prepared by pulsed laser deposition. The deposition system consists of a vacuum chamber equipped with a pulsed KrF excimer laser. The c-axis YBCO films are deposited in pure oxygen atmosphere at a growth rate of about  $0.5 \text{ nm/s}$  from a stoichiometric YBCO target. The optimal conditions for the samples are obtained at a substrate temperature of  $790^\circ\text{C}$  and  $0.28 \text{ mbar}$  oxygen pressures [15]. The as-deposited films were all c-axis oriented, with a typical thickness of  $500 \text{ nm}$  and  $T_c$  of  $89 \text{ K}$ .

The main difficulty for double side deposition is a direct contact between the substrate and the heater plate that usually induces some visible defect on the heater-facing surface. By inserting a thin Si-wafer between the substrate and the heater seemed to have solved the problem. This not only prevents the backside of the polished substrates from contamination during the deposition of the first film, but also works well for the second side deposition. As to keep the minimum degradation of the first side and to optimize the highest performance of the second side, both films are deposited at the same substrate temperature and oxygenation environment.

The features of the as-deposited YBCO thin films were analyzed by X-ray diffraction, atomic force microscopy (AFM) and resistivity measurements, respectively. The microwave properties are measured by microstrip resonator technique. On the one side of the films the designed pattern was transferred by photolithography and wet etch methods. The other side of superconducting YBCO was need to serve as ground plane. The sample was put into a gold-coated aluminum designed housing with SMA connectors. The package was placed in a vacuum tube and immersed in liquid nitrogen. We used a Lake Shore 330 autotune temperature

controller to control the temperature of the sample to be better than 0.1 K. The temperature dependence of the resonance frequency  $f(T)$ , frequency shifts  $\Delta f(T)$  and the forward transmission coefficient  $S_{21}$  were measured by a HP8510C microwave vector network analyzer at various temperatures.

### 3. RESULTS AND DISCUSSION

The typical  $\theta$ - $2\theta$  X-Ray diffraction patterns for both side of YBCO films are shown in Fig. 1. Apart from the substrate reflections, only  $(00\ell)$  peaks are observed in both cases, indicating

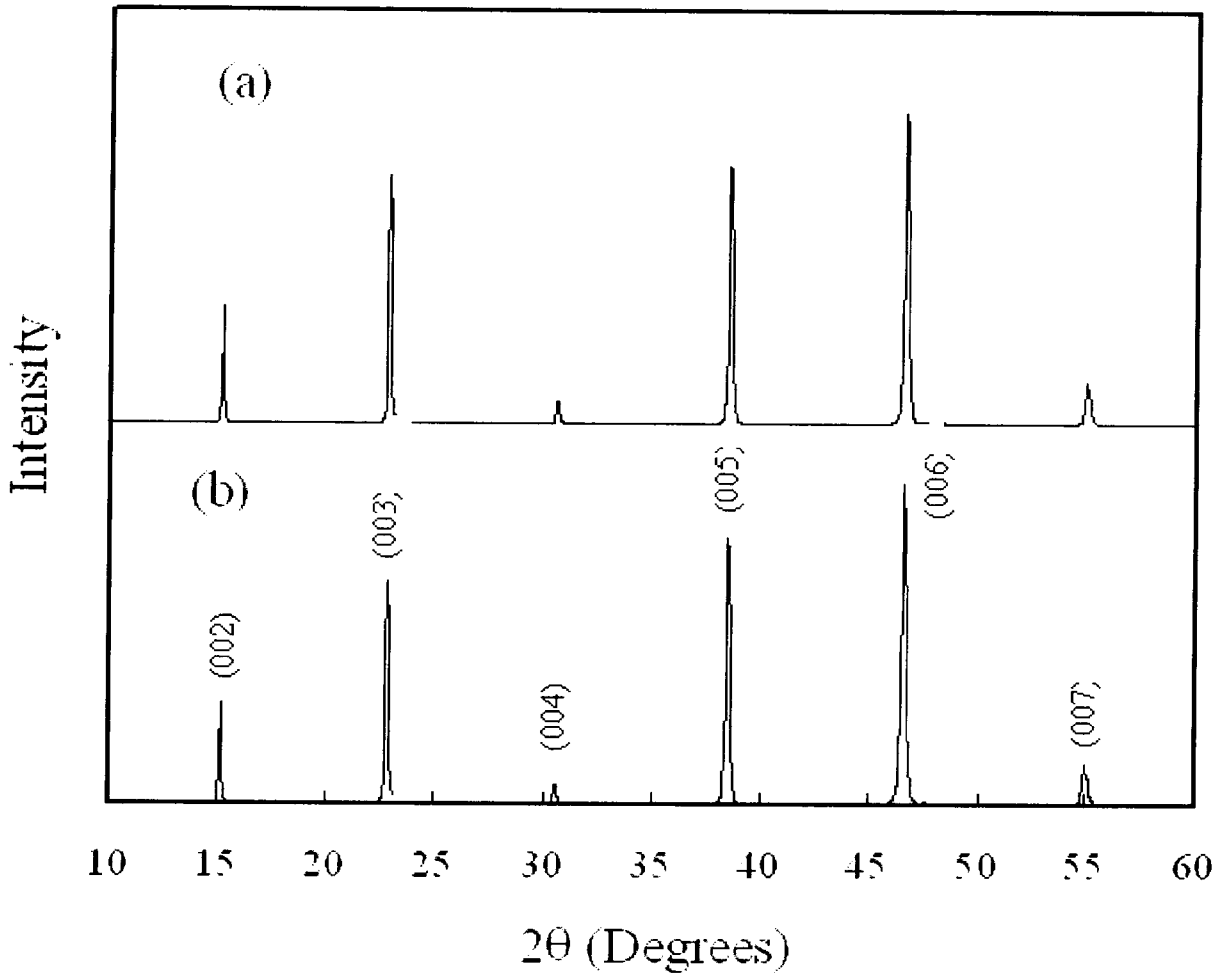


Fig. 1. The  $\theta$ - $2\theta$  X-Ray diffraction pattern for (a) first and (b) second side of YBCO double side film grown on LAO substrate.

the excellent c-axis oriented crystallinity of the films and epitaxial relationships with the substrate. The c-axis lattice parameter for both films is essentially the same with  $c = 1.168$  nm.

Fig. 2(a) and 2(b) depict the images of the surface morphologies of the YBCO films deposited the first and second side of the substrate, respectively. It is evident that the microstructure of the films displays a three-dimensional (3D) island-like morphology. The average grain size of the film is about 330 nm. The scanned area of the AFM image was  $2 \times 2 \mu\text{m}^2$  and the vertical scale was 25 nm, respectively. It is evident that the grain morphology of the first side is markedly different from that of the second side. The appearance of agglomerated grains is believed to result from high-temperature annealing effect during the deposition of the second side. Nonetheless, it appears that the annealing does not alter the basic nature of the film significantly, except for inducing grain coalescence, if the thickness of the film is beyond some threshold value.

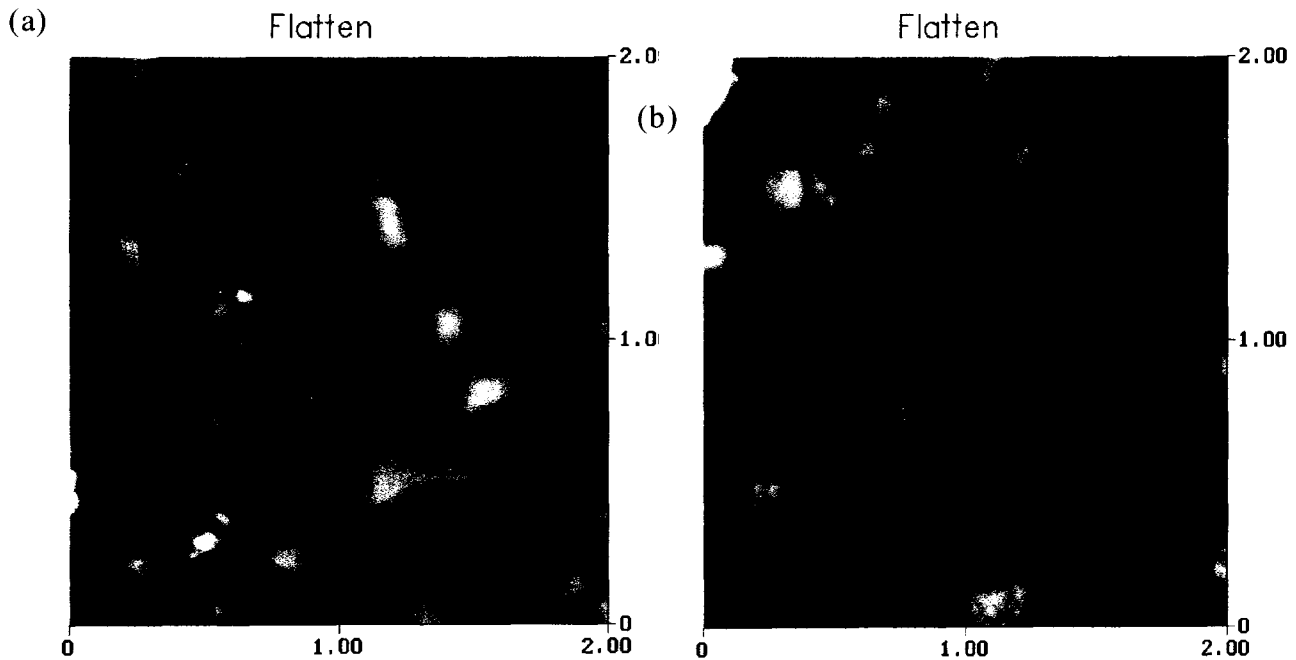


Fig. 2. (a) The images of the surface morphologies of the YBCO films deposited the first and (b) second side of the substrate, respectively. The scanned area of the AFM image was  $2 \times 2 \mu\text{m}^2$  and the vertical scale was 25 nm, respectively.

The critical temperature and superconducting transport properties of YBCO film were measured by standard four-probe technique. The  $R(T)/R(290\text{K})$  curves in Fig. 3 show that in the optimized conditions both sides of YBCO grown on  $\text{LaAlO}_3$  exhibit a metallic behavior with a sharp transition to the superconducting state at a temperature higher than 89 K. In comparison with that of the second film, slight degradation of the superconducting properties of the first one is found. The transition width in the both cases is less than 1K. Considering the severe thermal cycling experienced by the first YBCO film, the present results are, in fact, quite remarkable as one of the films may serve as an excellent ground plane for microwave devices.

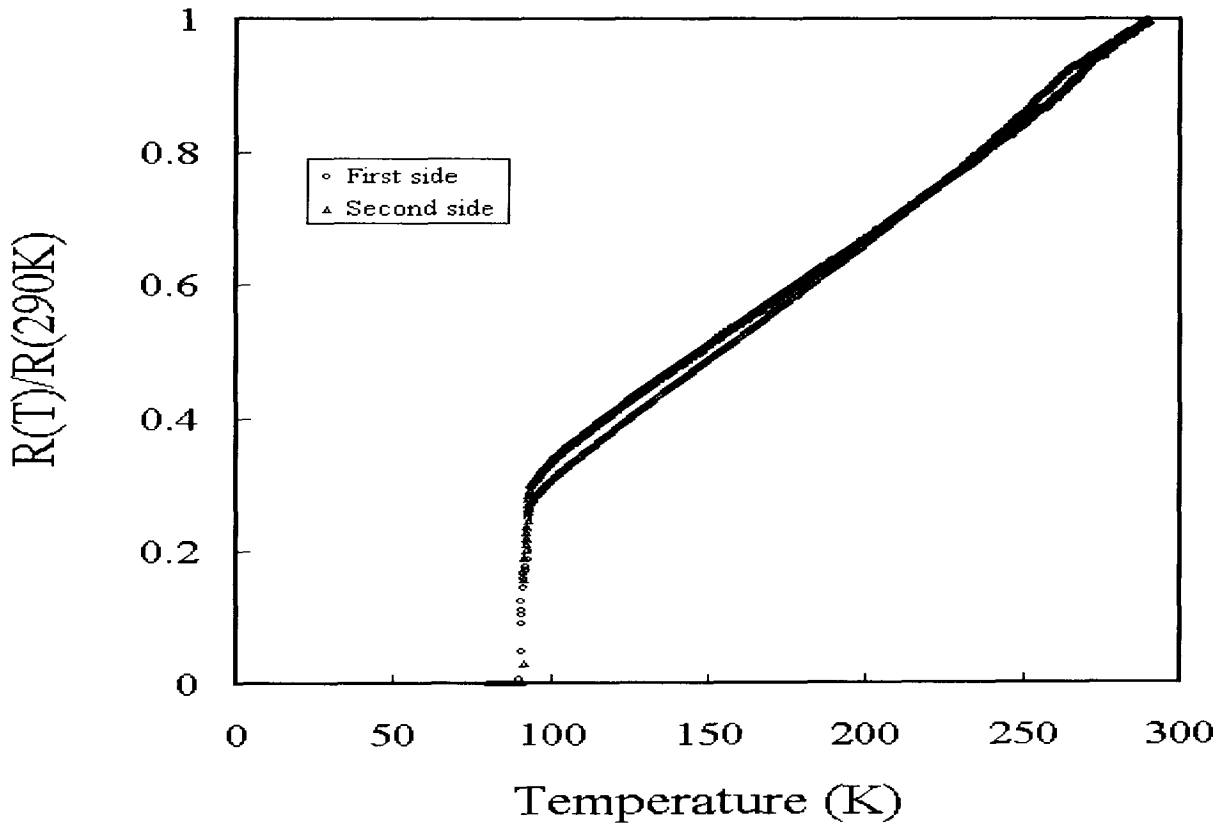


Fig. 3. The  $R(T)/R(290\text{ K})$  versus temperature for two sides of a YBCO thin film grown on  $\text{LaAlO}_3$ .

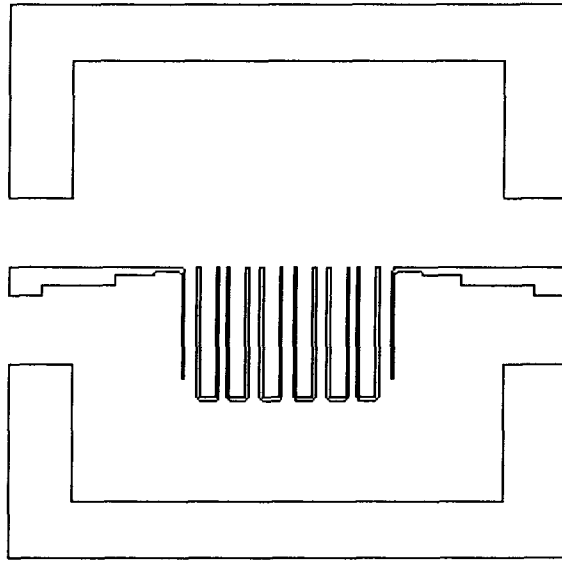


Fig. 4. A 6-pole microstrip hairpin-type band-pass filter.

The main aim of this work is to fabricate microwave filters using YBCO thin film by coupling a series of microstrip resonators on a relatively small area. In our design, a 6-pole microstrip hairpin-type band-pass filter, as depicted schematically in Fig. 4, was first simulated by “ANSOFT” software to demonstrate a central frequency of 8.16 GHz with 250 MHz bandwidth. The line width of the filter is 50  $\mu\text{m}$ . The coupling gap between the microstrip feeding line and the hairpin-type resonator is about 228  $\mu\text{m}$ . Fig. 5 shows the transmission ( $S_{21}$ ) and reflection ( $S_{11}$ ) of the 6-pole hairpin band-pass filter, measured at 78 K. The measured center frequency and bandwidth are 8.25 GHz and 250 MHz, respectively. These measured results are very close to the designed values. The central frequency has a slight shift of about 90 MHz with an apparent broadening in the high frequency side. The measured responses have insertion loss smaller than 0.5 dB. However, the rounding and unwanted dips at band-edges were observed. We believe that these may have been caused by the edge roughness resulting from patterning and etching processes. This might be further improved by using proper

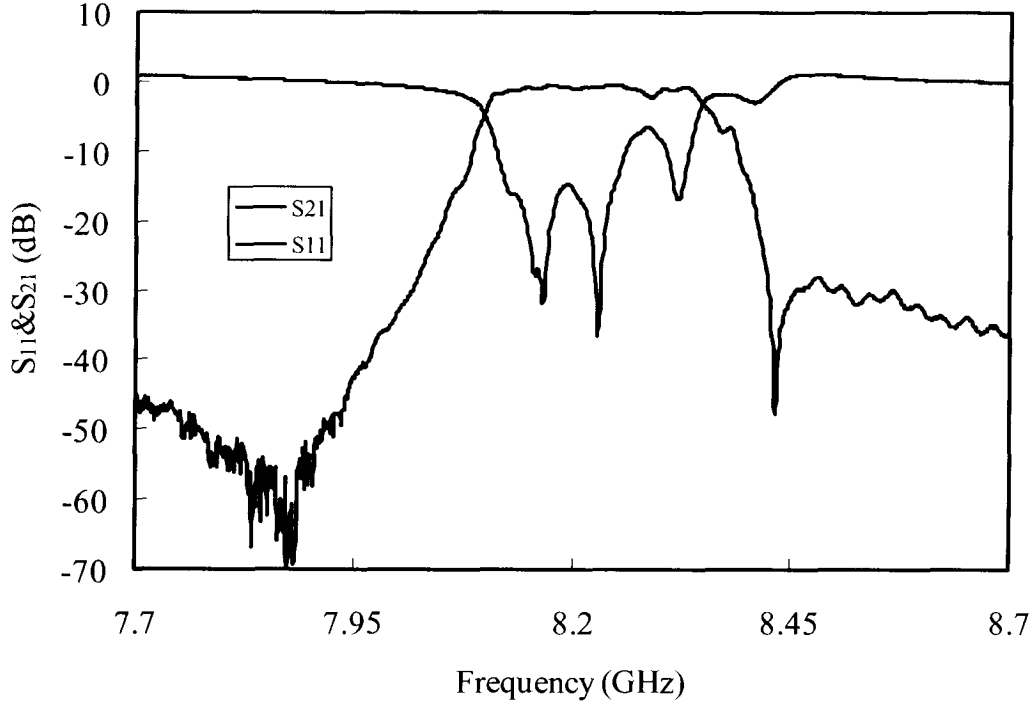


Fig. 5. The transmission ( $S_{21}$ ) and reflection ( $S_{11}$ ) of the 6-pole hairpin band-pass filter, measured at 78 K.

processing technique. Nonetheless, we note that the current results have already demonstrated a significant improvement in loss over its metallic counterpart. Fig. 6 shows microwave transmission  $S_{21}$  versus frequency for several temperatures. The center frequency shifts to the lower frequency by as much as 450 MHz from 55 K to 87.5 K. The temperature dependence of resonance frequency, which is due to the change of the London penetration depth, is shown in Fig. 7. The resonance frequency shows a rapid shift for  $T > 80$  K. Furthermore, as  $T > 80$  K, drastic degradation in insertion loss was observed. From the practical point of view, it is, in fact, showing the robustness of the current scheme, which is sustainable to temperatures well above the liquid nitrogen temperature. Patterns with lower central frequencies around 2 GHz restricted in a centimeter-square area are currently under design to harvest the great application potential of the double-sided HTS films with more compact device sizes.

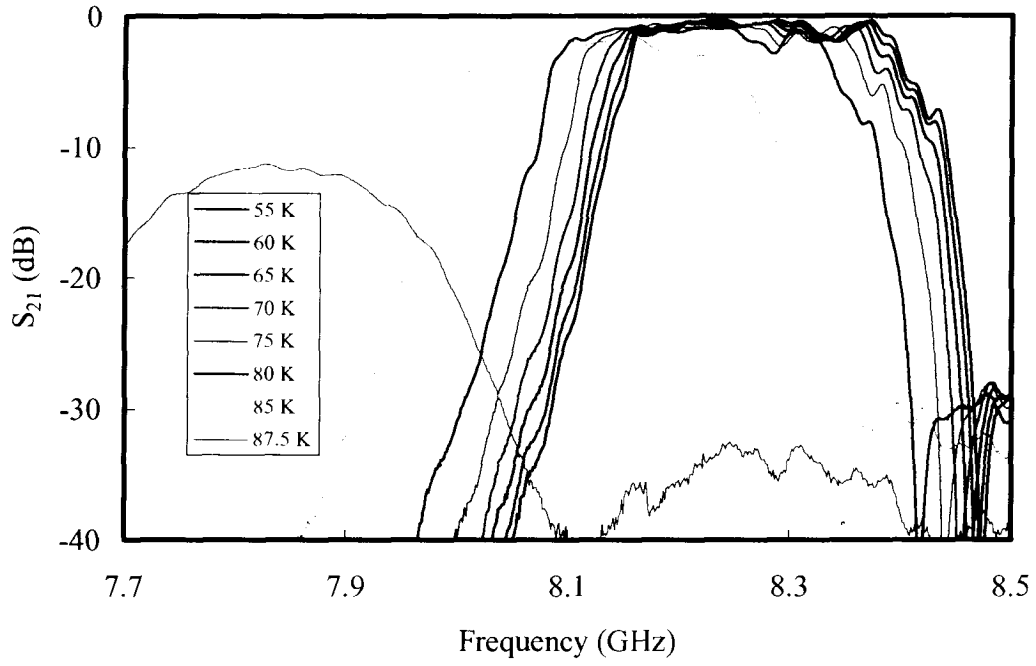


Fig. 6. Shows microwave transmission  $S_{21}$  versus frequency for  $T = 55, 60, 65, 70, 75, 80, 85$ , and  $87.5$  K.

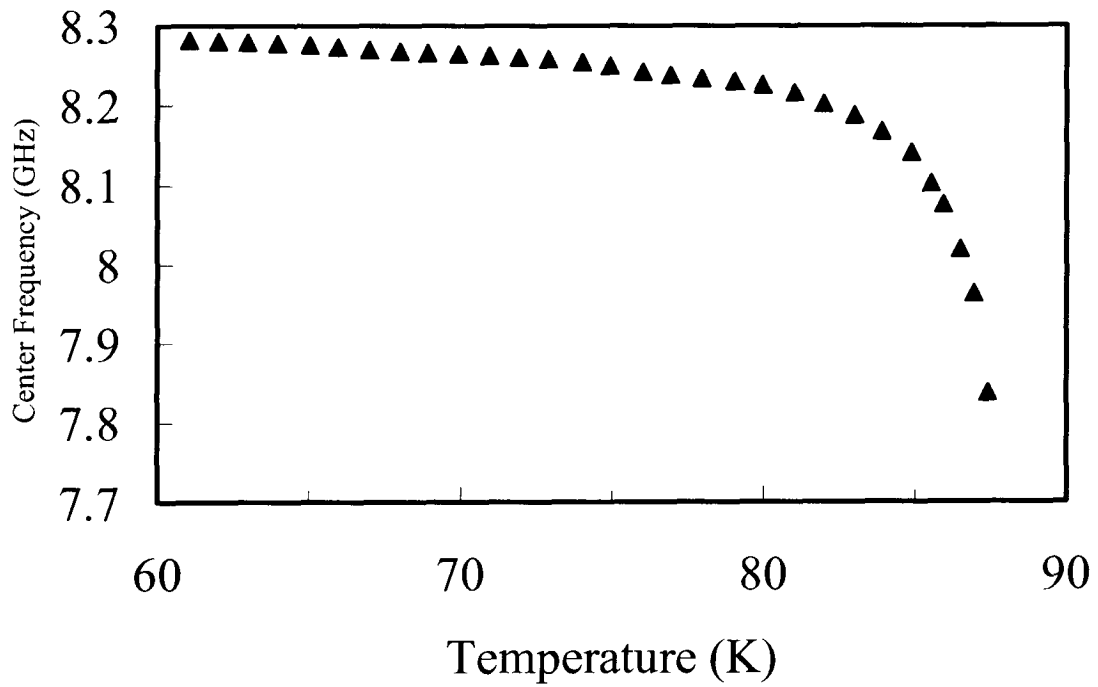


Fig. 7. The temperature dependence of resonance frequency in the 6-pole microstrip hairpin-type band-pass filter.

#### 4. SUMMARY

The designs of 6-pole hairpin-type microstrip band-pass filters with center frequency at 8.25 GHz have been successfully implemented on double-side YBCO HTS films. The measured responses with insertion loss smaller than 0.5 dB have been routinely achieved. The rounding and unwanted dips at band-edges roughness caused by etching processes, however, need to be further improved. Shifting of central frequency with temperature may be resolved by using, perhaps, frequency agile schemes such as using voltage-biased ferroelectric templates in our future works. Moreover, a novel design of the filter at central frequencies around 2 GHz with a more compact size is necessary to be developed in the near future.

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