EXTENDED ABSTRACT: THIN FILM SRF APPLICATIONS BEYOND ACCELERATORS

N. Klein, Forschungszentrum Jülich, D-52425 Jülich, Germany

Abstract

High-temperature superconducting thin films offer unique properties which can be utilised for a variety of high-frequency device applications in many areas related to the strongly progressing market of information technology. One important property is a low level of microwave absorption at temperatures attainable with low power cryocoolers. This unique property has initiated the development of various novel type of microwave devices and commercialised subsystems with special emphasis on application in advanced microwave communication systems. The second important achievement related to efforts in oxide thin and multilayer technology was the reproducible fabrication of low-noise Josephson junctions in high-temperature superconducting thin films. As a consequence of this achievement, several novel non-linear high-frequency devices, most of them exploiting the unique features of the AC-Josephson effect, have been developed and found to exhibit challenging properties to be utilised in basic metrology and Terahertz technology.

INTRODUCTION

Since the topic of this lecture was published recently in an extended review [1], only the key issues are addressed briefly and some personal statements emphasizing their status and potential are made. In addition, a few updated remarks on the potential of magnesium-diboride (MgB_2) will be presented. These remarks represent my subjective point-of-view on this subject.

Among the radio frequency (rf) applications of superconductors, rf cavities nowadays range as number one wit respect to their current market position. However, since microwave communication has experienced a tremendous growth over the last decade, even small market niches, where the extraordinary rf properties of superconducting materials can be utilised, are worth to be explored emphasising a further growth of the worldwide sc market.

HTS FILTERS

Planar bandpass filters based on thin films of high-temperature oxide superconductors (HTS) are currently the filters which exhibits the highest performance in comparison to other high-Q filter types such as cavity- or dielectric filters. In particular, the small possible bandwidth, low insertion loss and steep skirts (due to very large number of poles and high-Q values) represent the most challenging features, which have become possible due to the low surface resistance of sc films, novel types of filter topology and the – in comparison to dielectric and cavity filters – extremely small fabrication tolerances determined by photolithography. Drawbacks are the limited power handling capability determined by the non-linear rf properties of HTS films, which restricts their applicability to receivers in most cases. However, cost and reliability issues determined by the need of cyrogenic cooling limits commercial applications to particular cases where the benefits of high filter performance are massive.

Currently, about one thousand cryogenic receiver units for base stations based on integrated low-power cryocoolers, sc filters and cooled amplifiers have been installed worldwide and significant benefits have been demonstrated within field-trials [2]. However, the relevance of such systems for the upcoming 3D mobile communication networks is not clear yet. Current research efforts are concentrating on extremely narrowband and tuneable filters, which are of particular relevance for military applications.

Fur a recent review about HTS filters the reader is referred to a recent review by Heinz Chaloupka (Univ. of Wuppertal, Germany) and myself [3]. Among other rf passive device applications of HTS, it is worth to mention that oxide superconductor are successfully in use for rf receiver coils for commercial NMR spectrometers [4].

POTENTIAL OF MgB_2

Recently, significant progress has been achieved in the growth of high-quality thin films of MgB_2 by a combined MOCVD / PVD process [5] and by thermal evaporation [6], the latter with emphasis on large-area wafer coating. According to our recent study of the surface impedance of MgB_2 films shown in Fig. 1, there is a temperature window between about 4 K and 15 K, where R_s of MgB_2 films is below that of niobium and high-quality epitaxial films of $YBa_2Cu_3O_7$ (YBCO) (a comparison with Nb_3Sn and NbN would shift the lower border of this temperature interval to higher temperatures). Due to the double-gap nature of MgB_2 the temperature drop of R_s below $T_c/2$ is determined by $\exp(-\Delta_{min}/kT)$, the minimum value of $\Delta_{min}/kT = 0.6 - 1$ results in a rather weak temperature drop of R_s. [7]. Therefore, the potential for rf cavity application appears to be rather low, but possible niches may arise for millimetre and THz applications, where e.g. the losses in the antenna structures may be reduced with respect to Nb or NbN. From cryogenic cooling point of view, 10 to 15 K can make a great difference to 4 K, in particular with regard to the cost and power efficiency of closed-cycle refrigerators.

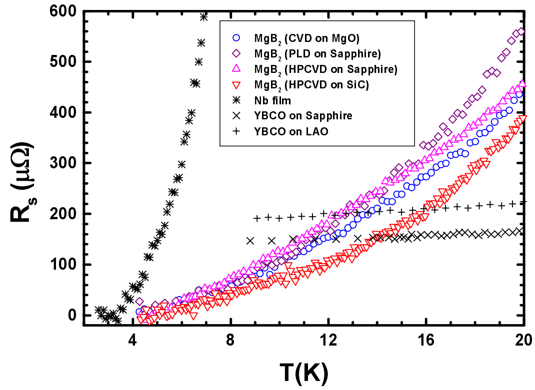

Figure 1: Surface resistance of high-quality MgB_2 films at 18 GHz in comparison to niobium and YBCO films.

ACTIVE HIGH-FREQUENCY DEVICES

As discussed in detail in [1] and [8], active high-frequency devices can be listed as follows:

- **SIS - quasiparticle mixers**: most sensitive THz-mixers for frequencies up to about 1 THz, mostly niobium.
- **Flux-flow devices**: Integrated (sub) THz receivers based on a flux-flow local oscillator for on-chip pumping of SIS mixers.
- **Hot-electron bolometers**: most sensitive THz-mixers for frequencies between about 1 THz and 3 THz, mostly NbN.
- **Transition edge bolometers**: most sensitive X-ray detectors (various low-T_c metallic super-conductors)[8].
- **HTS Josephson mixers** have a potential to beat the performance of cooled Schottly mixers above about 500 GHz with moderate operation temperature about 10 - 30 K (niobium).
- **Hilbert transform spectroscopy** represents an attractive method for emission-, transmission- and reflection spectroscopy in the frequency range from 100 GHz to about 4 THz (YBCO).
- **Josephson arrays in quantum voltage metrology**: common voltage standard used in all major National Standard Laboratories (only niobium), potential for secondary frequency standards by HTS Josephson arrays.
- **High-clock-frequency digital circuits and quantum bits**: promising technology for ultrafast digital circuits based on flux quantum logic and one of the most challenging technology for the realization of quantum bits and their circuit integration.

A detailed description of these devices and the physics behind. is given in [1] and [8].

Many of these devices are in use for inherent research applications. In fact, sc detectors in high-energy physics, astrophysics, and atmospheric physics play a dominant role right now.

RSFQ (rapid single flux quantum) based digital electronics has proved to beat the clock frequencies of GaAs in “small” circuits with about 10,000 junctions, and devices like ultrafast A/D converters have a potential for niche applications. As discussed in [1] HTS approaches for RSFQ curcuits are still in an infant state because of the difficulties associated with junction- and multilayer technology. MgB_2 is an attractive potential candidate, but an appropriate multilayer technology has not been developed yet. The realisation of quantum bits in niobium SQUID-rings disrupted by Josephson junctions [9] represents a challenging long-term effort of basic research aiming towards a possible realisation of quantum computation in the future.

REFERENCES

[1] N. Klein, “High-frequency applications of high-temperature superconductor thin films”, Reports on Progress in Physics 65 (2002) 1387 (see http://www.iop.org/EJ/journal/0034-4885).

[2] http://www.suptech.com/

[3] N. Klein and H. Chaloupka, „Superconducting Microwave Applications: Filters“, Elsevier Encyclopedia of Materials: Science and Technology, ISBN: 0-08-043152-6 (2003) pp. 1-9 (2003).

[4] http://www.bruker-biospin.com/

[5] Xinaghui Zeng et al., “In situ epitaxial MgB_2 thin films for superconducting electronics”, Letter to Nature, September 2002

[6] THEVA Newsletter 3, 2003, article 2 about efforts by B. Moeckly, STI

[7] B.B. Jin et al., „Anomalous coherence peak in the microwave conductivity of c-axis oriented MgB_2 thin films“, Phys. Rev. Lett. 91 (2003) 127006/1.

[8] M. H. Francombe, “Superconducting Film Devices”, Volume 3 of Handbook of ThinFilm Devices, Chapter 5 (2000) Academic Press.

[9] Y. Nakamura et al., “ Coherent control of macroscopoc quantum states in single-Cooper-pair “, Nature 298 (1999) 786 and NTT technical Review 1 (2003) (overview).