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[54] **SUPERCONDUCTING CIRCUIT ELEMENTS WITH METALLIC SUBSTRATE AND METHOD FOR MANUFACTURING THE SAME**

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[30] **Foreign Application Priority Data**

May 1, 1991 [EP] European Pat. Off. 91810336.7

[51] **Int. Cl.**[5] **H01L 39/14;** H01L 39/22; H01B 12/00; B05D 5/12

[52] **U.S. Cl.** **505/1;** 505/701; 257/33; 257/35; 257/39; 427/62

[58] **Field of Search** 505/1, 701, 833, 874; 357/5; 257/33, 35, 39

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J. J. Randall et al., "Preparation of Some Ternary Oxides of the Platinum Metals".
Journal of American Chemical Society, vol. 81, Jun. 5, 1959, pp. 2629–2631.

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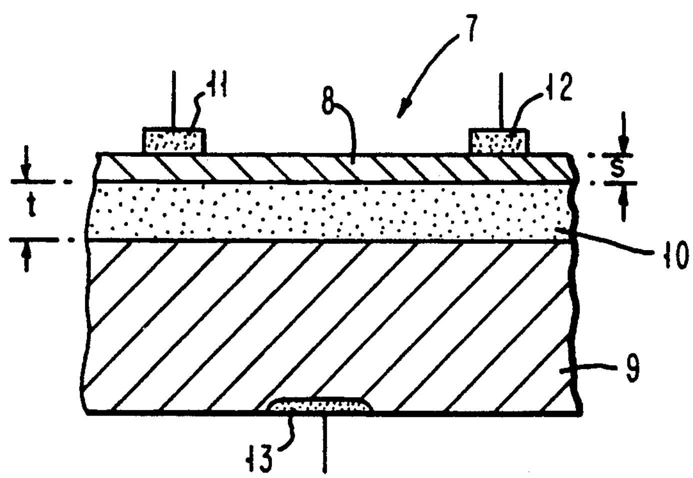
[57] **ABSTRACT**

These superconducting circuit elements, namely SNS heterostructures, such as, e.g. Josephson junctions and field-effect transistors, have a sandwich structure consisting of at least one layer of high-T_c superconductor material arranged adjacent to a metallic substrate, possibly with an insulating layer in between, the substrate, the superconductor and—if present—the insulator all consisting of materials having at least approximately matching molecular structures and lattice constants. Electrical contacts, such as source, drain and gate electrodes are attached to the superconductor layer and to the substrate, respectively. The electrically conductive substrate consists of a metallic oxide such as strontium ruthenate Sr_2RuO_4, whereas the superconductor layer is of the copper oxide type and may be $YBa_2Cu_3O_{7-\delta}$, for example. The insulator layer (**10**) may consist of $SrTiO_3$. The manufacture of these devices starts with the preparation of the substrate material from a 2:1,1 molar ratio of $SrCO_3$ to RuO_2 and involves a floating zone melting process yielding single crystals of the strontium ruthenate Sr_2RuO_4 material onto whose (001) surface the superconductor layer as well as the barrier layer can be epitaxially deposited.

11 Claims, 2 Drawing Sheets



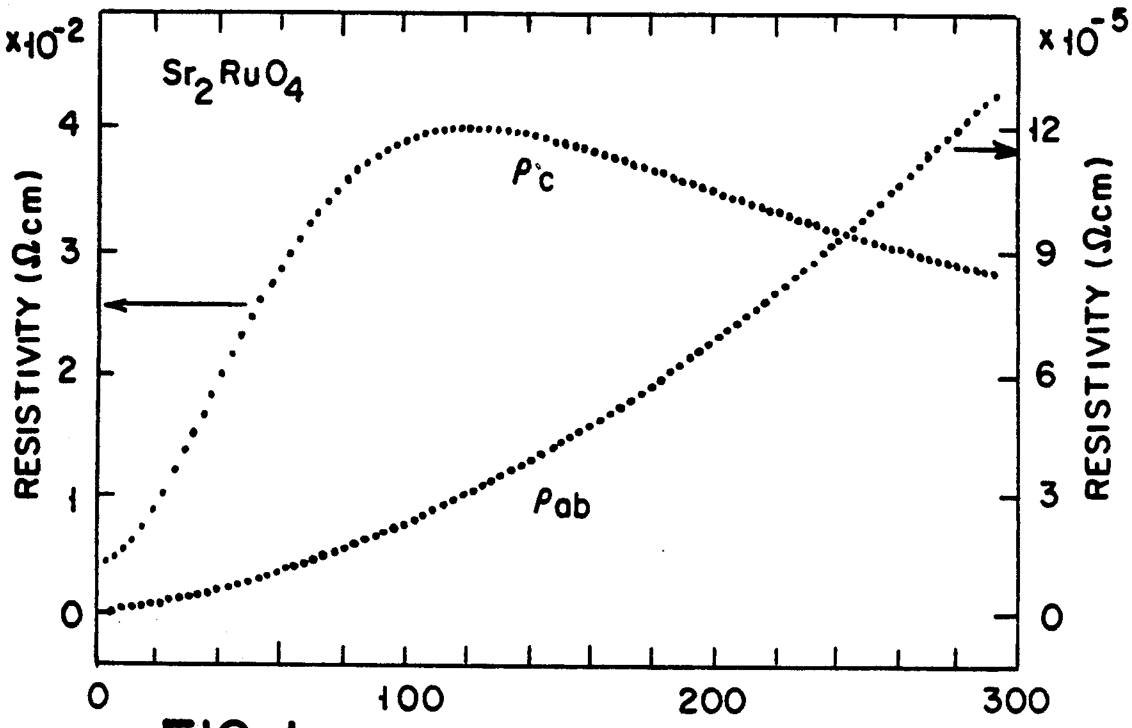

x10^-2
Sr2RuO4
4
3
2
1
0
RESISTIVITY (Ωcm)
ρc
ρab
x10^-5
12
9
6
3
0
RESISTIVITY (Ωcm)
0
100
200
300
TEMPERATURE (K)

FIG. 1

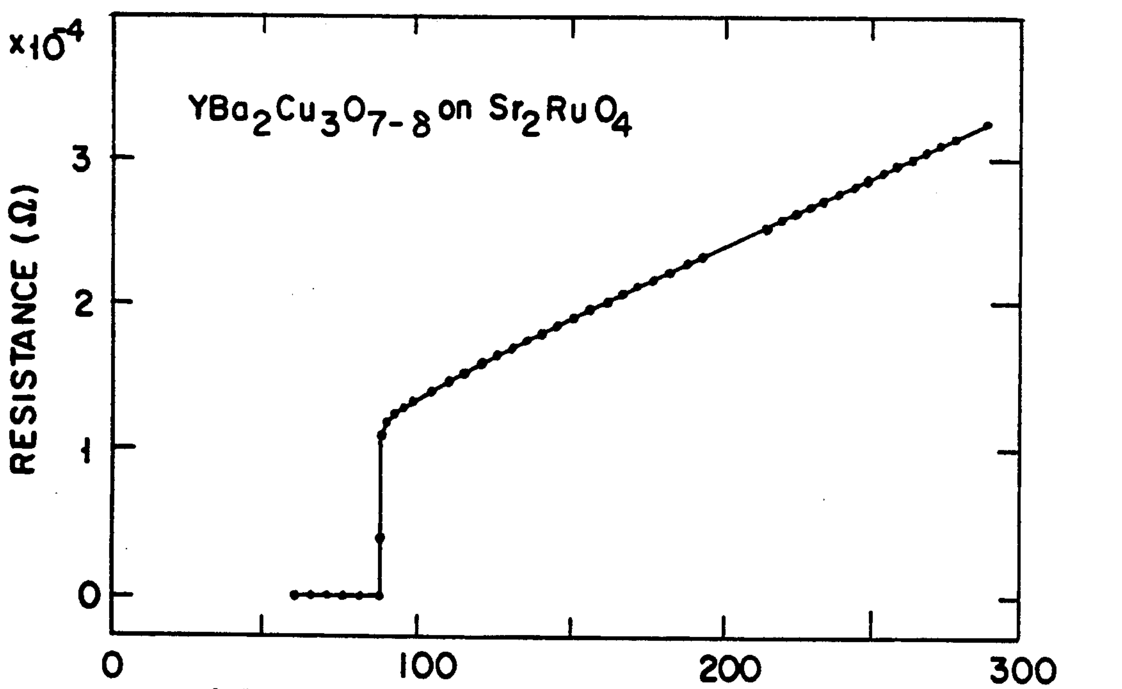

x10^-4
YBa2Cu3O7-δ on Sr2RuO4
3
2
1
0
RESISTANCE (Ω)
0
100
200
300
TEMPERATURE (K)

FIG. 2

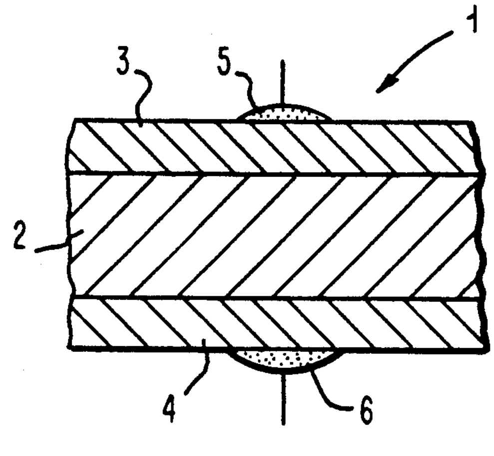


FIG. 3

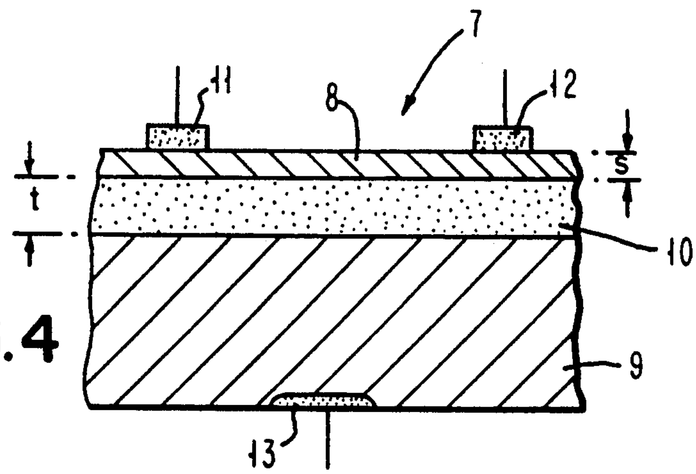


FIG. 4

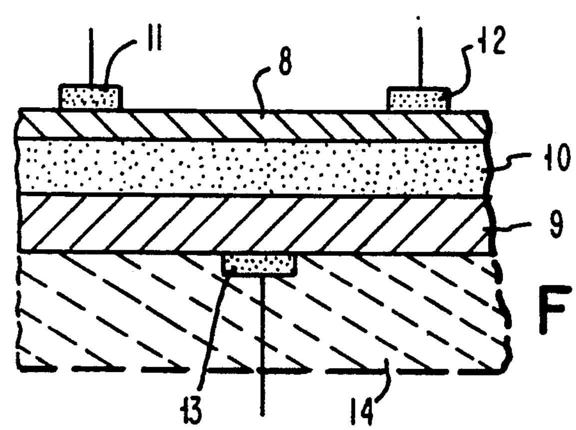


FIG. 5

SUPERCONDUCTING CIRCUIT ELEMENTS WITH METALLIC SUBSTRATE AND METHOD FOR MANUFACTURING THE SAME

BACKGROUND

This invention relates to superconducting circuit elements, namely heterostructures such as SNS Josephson junctions and field-effect transistors, having a sandwich structure consisting of at least one layer of high-T_c superconductor material arranged adjacent to a metallic substrate, having an insulating layer interposed between the high T_c material and the metallic substrate. Both the substrate and the insulator consist of materials having structural properties sufficiently similar to those of the superconductor so that mechanical and chemical compatibility is guaranteed.

For device applications of high-T_c superconductors, it is desirable to find electrically conductive materials, in particular metals, which are compatible with the high-T_c superconductor materials. Compatibility in this context means a best possible match of the respective lattice constants, and the absence of deleterious diffusion effects at the interfaces of the materials involved. These materials may be used, for example, in thin film form for SNS heterostructures (where S stands for superconductor, and N stands for normal metal), or they may serve as the bulk substrate in a field-effect transistor among other applications.

European application EP-A-0 409 338 discloses a planar Josephson device of the type where at least one layer of non-superconducting material is arranged between two layers of a superconductor material. In one embodiment described, the superconductor is $YBa_2Cu_3O_{7-\delta}$ and the non-superconductor is silver sulphate Ag_2SO_4. The silver sulphate being connected to the superconductor through layers of silver which serve to prevent diffusion of the sulphate into the superconductor.

The existence of an electrical field-effect in copper oxide high-T_c superconductors (although later found to be very small) has already been reported by U. Kabasawa et al. in Japanese Journ. of Appl. Phys. 29 L86, 1990, and EP-A-0 324 044 actually describes a three-terminal field-effect device with a superconducting channel. Electrical fields are used to control the transport properties of channel layers consisting of high-T_c superconductor materials. While this seemed to be a promising approach, growth studies of such devices have shown that in the suggested configuration, the ultrathin superconducting layers readily degrade during deposition of insulator layer and top electrode.

The lattice constant matching problem has been tackled by using doped and undoped versions of the same material. In particular, the substrate, is used as the gate electrode of a field-effect transistor of the MISFET type. The substrate consists of conducting niobium-doped strontium titanate. Onto that substrate, a barrier layer consisting of undoped strontium titanate is epitaxially grown, and onto the latter the current channel layer consisting of the superconducting $YBa_2Cu_3O_{7-\delta}$ is epitaxially deposited. It has been found (cf. H. Hagesawa et al., Jap. Journ. Appl. Phys., Vol. 28 (1989) L2210) that during film growth a thin insulating surface layer forms on the Nb-doped $SrTiO_3$, reducing the sensitivity of the device. The formation of this layer is possible due to a diffusion of Nb atoms from the gate/insulator interface into the bulk of the gate electrode.

SUMMARY OF THE INVENTION

It is an object of the present invention to overcome these disadvantages of the prior art. In accordance with the invention, metallic strontium ruthenate (or strontium ruthenium oxide) Sr_2RuO_4 is used as substrate material for the high-T_c superconductor and circuit elements formed from the high-T_c superconductor. These superconducting circuit elements, namely SNS heterostructures, such as, e.g. Josephson junctions and field-effect transistors, have a sandwich structure consisting of at least one layer of high-T_c superconductor material arranged adjacent to a metallic substrate, possibly with an insulating layer in between, the substrate, the superconductor and —if present—the insulator all consisting of materials having at least approximately matching molecular structures and lattice constants. Electrical contacts, such as source, drain and gate electrodes are attached to the superconductor layer and to the substrate, respectively. The electrically conductive substrate consists of a metallic oxide such as strontium ruthenate Sr_2RuO_4, whereas the superconductor layer is of the copper oxide type and may be $YBa_2Cu_3O_{7-\delta}$, for example. The insulator layer may consist of $SrTiO_3$. The manufacture of these devices starts with the preparation of the substrate material from a 2:1,1 molar ratio of $SrCO_3$ to RuO_2 and involves a floating zone melting process yielding single crystals of the strontium ruthenate Sr_2RuO_4 material onto whose (001) surface the superconductor layer as well as the barrier layer can be epitaxially deposited.

BRIEF DESCRIPTION OF THE DRAWING

FIG. **1** shows the resistivity ρ_c-versus-temperature characteristic of Sr_2RuO_4;

FIG. **2** is a diagram showing the resistance of a $YBa_2Cu_3O_{7-\delta}$ film grown on a Sr_2RuO_4 substrate in dependence on temperature;

FIG. **3** shows an SNS heterostructure with a Sr_2RuO_4 substrate;

FIG. **4** is an inverted MISFET structure using a Sr_2RuO_4 substrate;

FIG. **5** shows essentially the device of FIG. **4** with a supporting layer.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The prior art problem of undesired surface layers on the Nb-doped $SrTiO_3$ can be avoided if substrates are used as gate electrodes which are intrinsically metallic and that do not rely on dopants to induce metallic behavior. However, the intrinsically metallic substrate must be compatible with the high-T_c superconductor material.

Most of the high-T_c superconductor materials known today have very similar molecular structures and essentially the same lattice constants. Examples of high-T_c superconductors of the copper oxide type which can be used in connection with the present invention are listed in the table below, together with the respective reference where a description can be found:

Superconductor Composition	Reference
Tl—Ba—Ca—CuO	EP-A-0 332 309
Tl—Ba—Ca—Y—CuO	EP-A-0 368 210

-continued

Superconductor Composition	Reference
Bi—Sr—Ca—CuO	EP-A-0 332 291
	EP-A-0 362 000
	EP-A-0 366 510
Bi—Pb—Sr—Ba—CuO	EP-A-0 348 896
Bi—Pb—Sr—Ca—CuO	EP-A-0 400 666
La—Y—Bi—Sr—CuO	EP-A-0 287 810
Eu—Ba—CuO	EP-A-0 310 246
Yb—Ba—CuO	EP-A-0 310 247
Sr—La—CuO	EP-A-0 301 958

In addition to the high-T_c copper oxide superconductor materials of which examples are listed above, there are some other high-T_c superconductor materials known which do not rely on copper but other elements, such as bismuth, for example. One such material is $Ba_{0,6}K_{0,4}BiO_3$ which was described by R. J. Cava et al., "Superconductivity Near 30K Without Copper: The $Ba_{0,6}K_{0,4}BiO_3$ Perovskite", Nature, Vol. 332, No. 6167, pp. 814–816 (1988). The common characteristic of all known high-T_c superconductor materials which may be used in connection with the invention is that they have a perovskite or perovskite-related structure.

Apparently, of all high-T_c superconductor materials known so far, $YBa_2Cu_3O_{7-\delta}$ is the one best investigated. This material and methods for its manufacture are, for example, described in the following references: EP-A-0 282 199, EP-A-0 285 168, EP-A-0 286 823, EP-A-0 301 655, EP-A-0 310 248, EP-A-0 311 804, EP-A-0 321 862, EP-A-0 341 788, EP-A-0 349 444, EP-A-0 405 352.

Without intending to be restrictive, the description of the invention given below will use $YBa_2Cu_3O_{7-\delta}$ (with $0\leqq\delta\leqq1$) as an example of a high-T_c superconductor material, with the understanding that any other high-T_c superconductor material can be used instead, provided its molecular structure and lattice constants are sufficiently close to those of strontium ruthenate Sr_2RuO_4, and this is the case at least with all known high-T_c copper oxide superconductors and the bismuth oxide compound mentioned above.

In accordance with the present invention, the disadvantages of the prior art are overcome by superconducting circuit elements having a multilayered structure, comprising at least one layer of a high-T_c superconductor material arranged adjacent to a substrate consisting of a metallic conductor material having a molecular structure and lattice constants which at least approximately match those of said high-T_c superconductor material, the circuit elements being characterized in that said high-T_c superconductor material is of the perovskite-related type and that said electrically conductive substrate consists of strontium ruthenate Sr_2RuO_4.

The existence of Sr_2RuO_4, as a bulk material and a paramagnetic electrical conductor, is already known from reports by J. J. Randall et al., "The Preparation of Some Ternary Oxides of the Platinum Metals", J. Am. Chem. Soc. Vol. 81 (1959) pp. 2629–2631, and by A. Callaghan et al., "Magnetic Interactions in Ternary Ruthenium Oxides", Inorganic Chem., Vol. 5, No. 9 (1966) pp. 1572–1576. Of course, at the time of these reports, the high-T_c copper oxide superconductor materials were still unknown. Single-crystals of Sr_2RuO_4 were grown for the first time by the inventors and revealed a highly conductive metallic in-plane behavior which was not before known from the ceramic Sr_2RuO_4 bulk material.

The method for manufacturing superconducting circuit elements in accordance with the invention is characterized by the following steps:

Weighing appropriate ratios of strontium carbonate $SrCO_3$ and ruthenium dioxide RuO_2, and grinding;

Mixing the powder with water and pressing it to form two rods;

Sintering the rods in air at a temperature of about 1300° C.;

Melting the rods in air in a floating zone melting process;

Growing samples from the melt having cylindrical shape with layers (a-b-planes) of strontium ruthenate Sr_2RuO_4 along the axis of the cylinder;

Cleaving the melt-grown samples to obtain single-crystal substrates having defined crystallographic surfaces;

Rinsing the substrate in a cleaning solvent;

Attaching the single crystal to the heater of a sputtering chamber and sputtering with the following parameters;

substrate heater block temperature: 700°–750° C.;
total pressure ($Ar/O_2=2:1$): 0,845 mbar;
plasma discharge: 150–170 V, 450 mA,
aftergrowth cooldown in $\simeq$ 0,5 bar O_2 lasting for $\simeq$ 1 hour;

Epitaxially growing on at least one (001)-surface of the Sr_2RuO_4 substrate a film of a high-T_c superconducting material, with the thickness of the superconductor film being in the range of 1 to 1000 nm;

Depositing metal pads onto the superconductor layer(s) to form electrical contacts;

Applying a metal pad to the surface of the substrate facing away from said superconducting layer to form an electrical contact.

Details of three embodiments of the invention will hereafter be described by way of example and with reference to the drawings in which:

FIG. 1 shows the resistivity ρ_c-versus-temperature characteristic of Sr_2RuO_4;

FIG. 2 is a diagram showing the resistance of a $YBa_2Cu_3O_{7-\delta}$ film grown on a Sr_2RuO_4 substrate in dependence on temperature;

FIG. 3 shows an SNS heterostructure with a Sr_2RuO_4 substrate;

FIG. 4 is an inverted MISFET structure using a Sr_2RuO_4 substrate;

FIG. shows essentially the device of FIG. 4 with a supporting layer.

A metallic substrate is highly desirable for thin film applications of high-T_c superconductor materials, such as, e.g., $YBa_2Cu_3O_{7-\delta}$, for a number of reasons:

It can be used as a gate electrode in a field-effect device.

It can be used as a shunt resistance.

It has a higher thermal conductivity than $SrTiuO_3$, and, therefore, allows denser packaging of the devices.

It offers a convenient electrical contact from the superconductor to the external world or to other devices.

The problem with the metals and alloys so far considered for use in connection with high-T_c superconductor materials is simply that none of them has a lattice that matches the lattice structure of the superconductor material in question to any useful extent. Also, in some cases, diffusion across the interface between the materials tends to destroy the ability to become superconducting. Accordingly, none of these metals has found an application together with a high-T_c superconductor, except, perhaps as a contact material.

In contrast, the paramagnetic Sr_2RuO_4 has a layered K_2NiF_4-structure and is a metallic conductor along its layers, with an excellent lattice match to copper oxide superconductors, such as $YBa_2Cu_3O_{7-\delta}$. At 300K, Sr_2RuO_4 is tetragonal with lattice constants of a=b=0.387 nm, and c=1,274 nm, as compared to $YBa_2Cu_3O_{7-\delta}$ which is orthorhombic with lattice constants of a=0.382 nm, b=0.389 nm, and c=1.17 nm. This small lattice mismatch (of about 1.3%) compares favorably even to that between $YBa_2Cu_3O_{7-\delta}$(001) and strontium titanate $SrTiO_3${100}, the latter being the standard insulating substrate for the growth of superconducting copper oxides, and which at 300K is cubic, with a=0.391 nm (as shown in EP-A-0 324 220).

FIG. **1** shows the resistivity ρ_c-versus-temperature characteristic measured at a representative Sr_2RuO_4 crystal. No corrections for inhomogeneous current density distribution had to be made. In the a-b plane, the resistivity ranges from $\rho_{ab}\simeq 10^{-4}\Omega$cm at room temperature down to $\rho_{ab}\simeq 10^{-6}\Omega$cm at 4.2K demonstrating the highly conductive metallic in-plane behavior of Sr_2RuO_4. The observed resistivity along the c-axis resembles that of the layered materials TaS_2 and graphite. Like Sr_2RuO_4, they exhibit a metallic behavior along the layers and a resistivity maximum between room temperature and 4.2K perpendicular to the layers.

Generally, when it is possible to grow Sr_2RuO_4 on $SrTiO_3$ and vice-versa, thin film devices become feasible where insulating, superconducting and metallic layers can be combined in any way.

To demonstrate their compatibility, thin films of $YBa_2Cu_3O_{7-\delta}$ were grown onto the a-b-plane of a Sr_2RuO_4 crystal with very satisfactory results. The diagram of FIG. **2** shows the resistance of such a film in dependence on the temperature, with a critical temperature T_c of 86K.

Referring now to FIG. **3**, there is shown an SNS heterostructure **1** comprising an electrically conducting Sr_2RuO_4 crystal forming a substrate **2** and carrying on both sides thin-film superconductor layers **3** and **4** consisting of $YBa_2Cu_3O_{7-\delta}$. As mentioned above, the lattice constants of the substrate material match the lattice constants of the superconductor material to such an extent that epitaxial growth of the superconductor films **3**, **4** onto the substrate **2** is possible without a problem. Contact terminals **5** and **6** are attached to superconductor layers **3** and **4**, respectively.

FIG. **4** shows a field-effect transistor **7** having an inverted MISFET-structure. In this structure, a superconducting $YBa_2Cu_3O_{7-\delta}$ film **8** of the thickness s is separated from a Sr_2RuO_4 crystal substrate **9** serving as a gate electrode, by an insulating $SrTiO_3$ barrier layer **10** of the thickness t. Besides the thickness s of the superconductor film **8**, the resistivity ρ_1 and the breakthrough field strength E_{BD} of the insulator layer **10** are crucial parameters. The required values for E_{BD} and for ρ_1 can be simply estimated, if space charge effects are neglected: To induce a surface charge density in superconducting film **8** which corresponds to the unperturbed density n of mobile charge carriers ($n\simeq 3 \ldots 5\times 10^{21}/cm^3$), the capacitor formed by substrate **9** and superconductor film **8** has to be biased with a voltage

$$V_G = \frac{qnst}{\epsilon_0\epsilon_i} \quad (1)$$

where q is the elementary charge, ϵ_0 and ϵ_1 are respectively the dielectric constants of the vacuum and of the barrier layer material. Equation (1) rewritten provides the condition for the breakdown field strength E_{BD}:

$$E_{BD} \geqq \frac{V_g}{t} = \frac{qns}{\epsilon_0\epsilon_i}. \quad (2)$$

Equation (2) implies that to modulate the carrier density n in high-T_c superconductors substantially, the product $\epsilon_1\times E_{BD}$ has to be of the order of 10^8 V/cm. (For comparison, SiO_2 has an $\epsilon_1\times E_{BD}$ product of 4×10^7 V/cm at room temperature.)

In addition, the normal-state resistivity ρ_1 of the insulator has to be sufficiently high to avoid leakage currents which result in an input loss $V_G\times I_G$, the latter factor being the gate current. For a typical case of $I_G<I_{DS}/100$ and $I_{DS}=10\mu A$, and an area of the substrate **9** of 1 mm^2, the resistivity ρ_1 must be higher than $10^{14}\Omega cm/\epsilon_1$ at operating temperature.

In view of these requirements, insulating layers with high dielectric constants are recommended. Therefore, $SrTiO_3$ is a good material for insulating barrier layer **10** because of its good compatibility with the growth of copper oxide superconductors, such as $YBa_2Cu_3O_7$. The compatibility of $YBa_2Cu_3O_7$ with $SrTiO_3$ has already been pointed out in EP-A-0 299 870 and EP-A-0 301 646.

The dielectric constant ϵ_1 of $SrTiO_3$ being between 40 and 300 (depending on the purity of the material), the breakdown field being on the order of 10^8 V/cm, and with an operating voltage $V_G=5$ V, equation (2) suggests that a monomolecular (i.e. unit cell) layer of superconductor material would meet the requirements. Accordingly, with s=1,2 nm and $\epsilon_1=260$ and a carrier density $n=3\times 10^{21}$ cm^{-3}, equation (1) yields a value of $t\simeq 20$ nm.

The manufacture of the Josephson junction heterostructure of FIG. **3** and of the inverted MISFET device in accordance with FIG. **4** preferably involves the following steps:

1. Appropriate ratios, molar ratios, for example, of strontium carbonate $SrCO_3$ and ruthenium dioxide RuO_2 are weighed with an accuracy of better than 1‰.
2. After grinding, the powder is mixed with water and pressed to form rods of, say, 5 mm diameter, one 10 mm in length, the other 100 mm in length, for example.
3. The rods are sintered on Al_2O_3 boats in air at about 1300° C.
4. Using the floating zone process, the rods are melted in air in a mirror cavity with focused infrared radiation, the short rod being used as the seed, the long rod being used as the feed material.
5. Single-crystals are grown from the melt. The melt-grown samples have cylindrical shape with layers (a-b-planes) of Sr_2RuO_4 grown along the axis of the cylinder.

The growth of the Sr_2RuO_4 crystals is complicated by the volatility of RuO_2 which leads to the segregation of SrO. To compensate for this segregation, an excess of RuO_2 must be used in the starting material. A molar ratio of 2:1,1 of $SrCO_3$ and RuO_2 is recommended to minimize the amount of segregated SrO. In order to grow large crystals, the amount of molten material as well as its composition should be kept constant. This is difficult to achieve probably owing to the continuous evaporation of RuO_2 and because of the low density of the rods.

6. The crystals are then cleaved.

Because of the layered structure of Sr_2RuO_4, the melt-grown samples can be cleaved easily, and single-crystals may be obtained from the interior part of the cylinder.

With this technique it is possible to grow a cylindrical Sr_2RuO_4 crystal of about 5 mm diameter and 10 mm length. Having prepared the single-crystal Sr_2RuO_4 substrate, the manufacture of the heterostructure **1** of FIG. **3** involves the following additional steps:

1. The substrate **2** is rinsed in acetone and propanol and attached to the heater of the sputtering chamber with silver paint, for example.
2. On the upper (001) surface of the Sr_2RuO_4 substrate **2**, a superconducting film **3** of, for example, $YBa_2Cu_3O_{7-\delta}$ is epitaxially grown by hollow cathode rf-magnetron sputtering, wherein the value of δ is preferably kept equal to zero, but can be made as large as 1. The sputter parameters used encompass a substrate heater block temperature of 700°–750° C., a total pressure ($Ar/O_2=2:1$) of 0,845 mbar, a plasma discharge of 150–170 V and 450 mA, and an after-growth cooldown in ≃0,5 bar O_2 lasting for ≃ 1 hour. The thickness of the superconductor film **3** can finally be in the range of 1 to 1000 nm.
3. The same step is repeated for the lower (001) surface of the Sr_2RuO_4 substrate **2** to form superconductor layer **4**.
4. Electrical contacts are then made in the form of indium dots, silver paint, or metal pads, such as gold pads **5** and **6**, for example, on the superconductor layers **3** and **4**, respectively.

The manufacture of the MISFET-structure **7** of FIG. **4** involves the following steps additional to the preparation of the Sr_2RuO_4 substrate **9**:

1. A {100}-oriented $SrTiO_3$ barrier layer **10** is epitaxially grown by reactive rf-magnetron sputtering at 6,7 Pa in an O_2/Ar atmosphere at 650° C. (temperature of the sample holder) as an insulator on top of the Sr_2RuO_4 substrate **9** and is polished down to the desired final thickness.
2. On top of the thinned barrier layer **10**, a superconductor film **8** (of $YBa_2Cu_3O_{7-\delta}$, for example) with the thickness s is sputtered.
3. Gold pads **11** and **12** are provided on top of the superconductor layer **8** to form source and drain contacts, respectively.
4. On the back side of the substrate **9**, a gate electrode **13** in the form of a metal layer, such as a gold layer, for example, is deposited.
5. Optionally, substrate **9** and gate electrode **13** may be arranged on an insulating support layer **14**, be it for stability, as indicated in FIG. **5**. Support layer **14** may again consist of $SrTiO_3$ and be epitaxially grown be reactive rf-magnetron sputtering. The thickness of this layer can be freely chosen.

From the measurements taken with several sample embodiments of the field-effect transistor in accordance with FIGS. **4** and **5**, it has been determined that the operating gate voltage V_G should be in the range between 0,1 and 50 V, preferably 5 V, the thickness s of the superconducting film should be in the range between 1 and 30 nm, and the thickness t of the insulating layer should be in the range between 3 and 100 nm.

In accordance with the invention, MISFET-type heterostructures consisting of high-T_c superconductor/$SrTiO_3$/Sr_2RuO_4 multilayers may be made which allow the application of electrical fields larger than 10^7 V/cm to the superconducting films. In these devices, electric field-effects generate changes in the channel resistance. The high-T_C superconductor films have a preferred thickness on the order of 10 nm and are operated with gate voltages well below 30 Volts. The channel resistivity changes can be attributed to equally strong changes of the carrier density in the high-T_c superconductor.

It should be noted that Sr_2RuO_4 can also be used in the form of thin films for certain applications. Those skilled in the art will understand that such films can be made with any of the conventional methods, such as electron beam evaporation, thermal evaporation, chemical vapor deposition, metalorganic vapor deposition, laser ablation, rf-magnetron sputtering, spinning-on, molecular beam epitaxy, etc., for example.

While this invention has been described with respect to plural embodiments thereof, it will be understood by those with skill in the art that changes in the above description or illustrations may be made with respect to form or detail without departing from the spirit or scope of the invention.

We claim:

1. A superconducting circuit element having a multilayered structure, comprising:

at least one layer of a high-T_c superconductor material arranged adjacent to a substrate consisting essentially of strontium ruthenate Sr_2RuO_4 having a molecular structure and lattice constant which at least approximately match those of said high-T_c perovskite superconductor material.

2. A superconducting circuit element in accordance with claim **1**, wherein said high-T_c superconductor material consists of $YBa_2Cu_3O_{7-\delta}$, and wherein $0 \leqq \delta \leqq 1$.

3. A superconducting circuit element in accordance with claim **1**, wherein:

two high-T_c superconducting layers are arranged adjacent said Sr_2RuO_4 substrate on opposite sides thereof; and

contact pads (**5**, **6**) are attached to said superconducting layers forming a Josephson junction.

4. A superconducting circuit element in accordance with claim **3**, wherein said high-T_c superconductor material consists of $YBa_2Cu_3O_{7-\delta}$, and wherein $0 \leqq \delta \leqq 1$.

5. A superconducting circuit element in accordance with claim **1**, wherein:

said Sr_2RuO_4 substrate is a single crystal; and

said superconducting layer is deposited on a (001) surface of said Sr_2RuO_4 substrate.

6. A superconducting circuit element in accordance with claim **5**, wherein said high-T_c superconductor material consists of $YBa_2Cu_3O_{7-\delta}$, and wherein $0 \leqq \delta \leqq 1$.

7. A superconducting circuit element in accordance with claim **1**, further comprising:

a barrier layer consisting of a material whose molecular structure and lattice constants at least approximately match those of the materials of said superconductor layer and of said Sr_2RuO_4 substrate arranged between said high-T_c superconductor layer and said Sr_2RuO_4 substrate.

8. A superconducting circuit element in accordance with claim **7**, further comprising:

first and second contact pads disposed on top of said high-T_c superconducting layer and forming source and drain electrodes, said source and drain electrodes defining a current channel; and a third contact pad attached to said substrate serving as a gate electrode, and forming a field-effect transistor.

9. A superconducting circuit element in accordance with claim **8**, wherein said high-T_c superconductor material consists of $YBa_2Cu_3O_{7-\delta}$, and wherein $0 \leqq \delta \leqq 1$.

10. A superconducting circuit element in accordance with claim **7**, wherein said barrier layer consists of strontium titanate $SrTiO_3$.

11. A superconducting circuit element in accordance with claim **10**, wherein said high-T_c superconductor material consists of $YBa_2Cu_3O_{7-\delta}$, and wherein $0 \leqq \delta \leqq 1$.

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