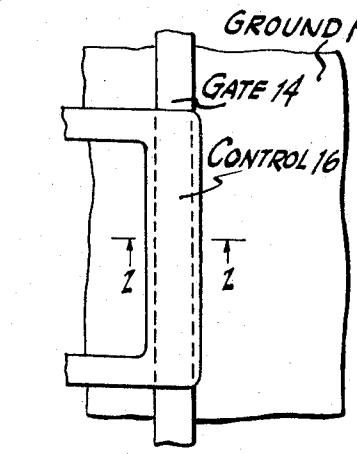
Jan. 31, 1967 C. M. WINE 3,302,152

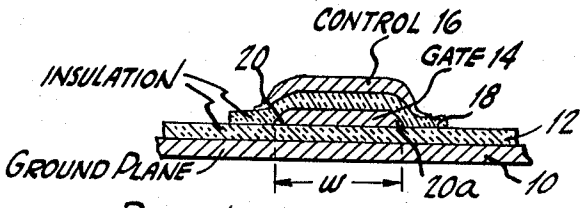
CRYOELECTRIC DEVICE

Filed Aug. 19, 1964



PRIOR ART

Fig. 1.



PRIOR ART

Fig. 2.

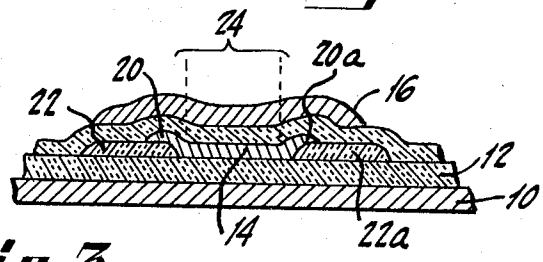


Fig. 3.

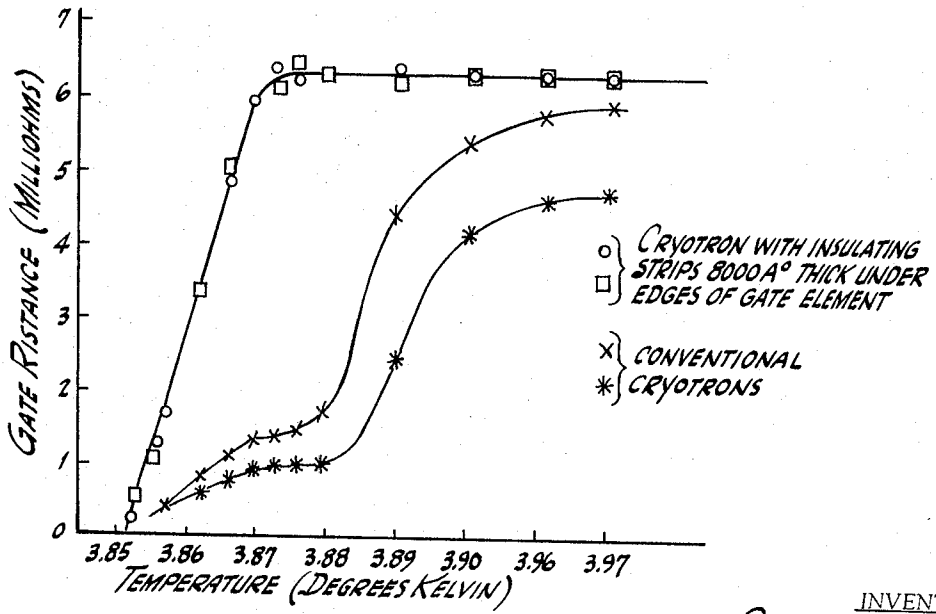


Fig. 4.

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CRYOELECTRIC DEVICE

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This invention relates to means for improving the current-carrying capacity of thin-film superconductor lines and is especially applicable to cryotrons.

A known thin-film superconductor transmission circuit includes a superconductor strip line lying on the insulated surface of a superconductor ground plane. The ground plane in close proximity to the line substantially reduces the inductance of the line, a desirable feature in many circuit applications. The strip line may be formed by vacuum depositing a metal, such as tin or lead, through a mask onto a substrate (the insulated surface). So made, the line is generally found not to be of uniform cross-section. Its edges taper, that is, they are thinner than the center portion of the line. This is believed to be due, among other things, to penumbra effects during the vapor deposition.

If one assumes the current carried by a superconductor line to distribute uniformly along the width of the line, the current density at the edges of a line such as discussed above is greater than that at the center of the line. Due to this non-uniform current density, at some value of current at which the center portion of the line remains superconducting, the current density at the edges of the line exceeds the "critical" value, that is, it becomes sufficient to drive the edges to the normal (resistive) condition. Once the edges are driven normal, the normal region rapidly spreads to the remainder of the line. Therefore, it is ordinarily necessary to operate the line at a lower level of current—one at which the current density at the edges is less than the critical value, than the bulk of the line can support.

The so-called "edge effects" discussed above are largely avoided according to the present invention by spacing the edges of the line further from the ground plane than the center portion of the line as, for example, by placing insulator strips beneath these edges. This substantially increases the inductance of the line at its edges, and consequently reduces the density of current flow at the edges.

The invention is discussed in greater detail below and is illustrated in the following drawings, of which:

FIGURE 1 is a plan view of a prior art in-line cryotron;

FIGURE 2 is a cross-section taken along line 2—2 of FIGURE 1;

FIGURE 3 is a cross-section through an in-line cryotron according to the present invention; and

FIGURE 4 is a graph illustrating the performance of the prior art cryotron as contrasted to the one in the present invention.

In the discussion which follows, a low-temperature environment, such as a few degrees Kelvin, at which superconductivity is possible, is assumed.

The cryotron of FIGURES 1 and 2 includes a ground plane **10**, which is formed of a superconductor, such as lead, and a thin insulating film **12**, which may be formed of silicon monoxide, located on the ground plane. A gate element **14** is located over the insulated ground plane and a control element **16** is located over the gate element. The gate element may be formed of a superconductor, such as tin, and the control element may be formed of a superconductor, such as lead. The two elements are insulated from one another by an insulating layer **18**, such as silicon monoxide.

The gate element **14** is for the purpose of carrying a current to some load such as a drive line of a superconductor memory. In one condition, the gate element is

superconducting and offers zero resistance to this flow of current. In another condition, current is passed through the control element **16** to produce a magnetic field of sufficient magnitude to drive the gate element from its superconducting to its "normal" (resistive) condition. In this second condition, the gate element exhibits a finite resistance to the flow of current.

The gate element **14** is normally fabricated by vacuum deposition through a mask. When made in this way, the edges **20**, **20***a* taper rather than being perpendicular to the insulator surface. A current passed through the gate element **14** tends to distribute uniformly over the width *w* of the gate element. Since the edges **20** and **20***a* are thinner than the remainder of the gate element, the current density at these edges tends to be greater than the current density within the remainder of the gate element. As a result of this non-uniform current density, the edges **20** and **20***a* tend to be driven normal at a value of current which the remainder of the gate element could otherwise support while in the superconductive state. As is well understood, these normal areas tend to spread to the remainder of the gate element, driving the entire gate element normal and limiting the current-carrying capacity of the gate element.

In the embodiment of the invention illustrated, strips of insulating material **22** and **22***a*, shown in FIGURE 3, are laid down on the insulator **12** prior to the time that the gate element is formed. The gate element is vacuum deposited onto the layer **12** with the edges **20** and **20***a* thereof on the insulator strips **22** and **22***a*. Thus, the edges **20** and **20***a* are spaced from the ground plane **10** a substantial distance greater than the bulk **24** of the gate element is spaced from the ground plane. The inductance of the gate element is a function of its spacing from the ground plane **10**. Accordingly, the inductance of the edges **20** and **20***a* of the gate element is substantially greater than that of the remainder of the gate element.

As is well understood in the cryoelectric art, if a current is applied to two superconductors in parallel, the current divides in inverse proportion to the inductance of the two conductors. In the present instance, the conductors which exhibit a high inductance can be considered to be the edge portions **20** and **20***a*, and the conductor exhibiting a low inductance can be considered to be the center region. Accordingly, when a current is applied to the gate element, it tends to distribute so that less of the current flows at the edges **20** and **20***a* than in the bulk **24**. Therefore, even though the gate element is thinner at its edges **20** and **20***a* and the current density accordingly tends to be greater there, the increased inductance at the edges reduces the amount of current flowing at these edges and tends to reduce the current density. The over-all result is that current flow through the gate element in the arrangement of FIGURE 3 is of more uniform density through out the width of the gate element than in the arrangement of FIGURE 2.

In plan view, the cryotron of FIGURE 3 has substantially the same appearance as the one shown in FIGURE 1.

Typical dimensions of an in-line cryotron such as shown in FIGURE 3 are:

Gate element **14**:
- width—10 mils
- film thickness—5000 A. (Angstroms)

Control element **16**:
- width—15 mils
- film thickness—5000 A.
- insulation layer thickness—8000 A.

Insulation strips **22** and **22***a*:
- width—5 mils. (These strips were overlapped by the edges of the gate element over an area 2 mils wide.) thickness—8000 A.

The principles of the invention are applicable not only to in-line cryotrons, but also to strip transmission lines, crossed-film cryotrons, and so on. A crossed-film cryotron is one in which the gate element extends at right angles to the control element. As in the case of in-line cryotrons, the gate element may be formed of a superconductor such as tin, and the control element may be formed of a superconductor such as lead.

To check the operation discussed above, four crossed-film cryotrons on ground planes were fabricated. A plot of the resistance of the cryotron vs. the temperature (the temperature being the factor varied) is shown in FIGURE 4. Two of the cryotrons were made with insulation strips under the edges of the gate electrode to space the edges further from the ground plane than the center region of the gate element similarly to what is shown in FIGURE 3, and two were conventional cryotrons in which the gate element was uniformly spaced from the ground plane. Except for the insulation under the edges of the gate elements in two of the cryotrons, they were in other respects substantially identical. The significant improvement in performance obtained with the crossed-film cryotrons of the present invention is believed to be self-evident from the curves.

As the cryotrons built were tested individually (rather than in tree configurations), temperature was made the variable and resistance was measured by passing a relatively small current through the gate element. This was to prevent run-away effects due to heating of the gate elements. However, as is well understood in this art, similar curves may be obtained with the temperature maintained constant at some value, such as 3° K. or 3½° K. and current employed as the variable or "running" parameter, providing these temperature effects are eliminated or compensated for.

What is claimed is:

1. A two-conductor transmission circuit comprising:
a superconductor ground plane; and
a thin-film superconductor strip line lying over and insulated from the ground plane both at its center and at its longer edges and exhibiting a substantially greater inductance at its opposite edges, by virtue of increased spacing at said edges from the ground plane, than at its center portion.

2. A two conductor transmission circuit comprising:
a superconductor ground plane;
insulation on one surface of the ground plane which is substantially thicker in certain regions thereof over the ground plane than in other regions thereof over the ground plane, and
a thin film superconductor strip which is thinner at its opposite edges than at its center lying on said insulation, the opposite edges of said strip lying on the thicker regions of the insulation and the center portions of the strip lying on the thinner region of said insulation whereby the strip exhibits a substantially greater inductance at its opposite edges than at its center portion.

3. A transmission circuit comprising:
a superconductor ground plane;
insulation on one surface of the ground plane, two spaced strips of which are substantially thicker than other portions of the insulation on the ground plane, said two spaced strips of insulation and the insulation between these strips lying over the ground plane; and
a thin film superconductor line which is thinner at its opposite edges than at its center lying on the insulation, the edges of said line lying on said thicker insulation strips and the center portion of said line lying on the relatively thinner portion of the insualtion, whereby the relatively thinner edges of said line are spaced substantially further from the ground plane than the center portion of the line.

4. A transmission circuit comprising, in combination:
a superconductor ground plane;
insulation on one surface of the ground plane;
a thin film superconductor line on said insulation, said line being thinner at its edges than at its center; and
additional insulation over the ground plane lying under the edges of the line spacing said edges a substantially greater distance from the ground plane than the center portion of the line.

5. A cryotron comprising:
a superconductor ground plane;
insulation on said ground plane;
a thin film superconductor gate element insulated from and lying over the ground plane, the element being thinner at its edges than at its center;
additional insulation under the edges of said gate element for spacing said edges substantially further from the ground plane than the center portion of the gate element; and
a thin film superconductor control element lying over and insulated from the gate element.

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