The best criteria for verifying the method are the experimental results; the investigations are in progress. Nevertheless, it is apparent from the above discussion that quite accurate results can be obtained by the eigenfunction method employing a small number of evanescent modes.

V. Conclusion

Starting from eigenfunction expansion of the fields inside the junction, a procedure to determine the impedance and admittance representations of a certain class of rectangular waveguides has been developed. The derivation of the expressions for the matrix entries is straightforward once the eigenfunctions of the junction are found. When the lateral boundaries of the junction coincide with the constant coordinate surfaces of a cylindrical coordinate system, closed-form expressions can be obtained for the eigenfunctions. However, for junctions with arbitrary cross sections, numerical methods have to be used to obtain approximate eigenfunctions. For many practical cases the eigenfunctions are in the form of the trigonometric and/or the Bessel's function and can easily be used in appropriate expressions.

One of the features of the method is that it can be used at any frequency. This is because matrices covering all the modes in the connecting waveguides are found at the beginning, and then at a given frequency the evanescent modes are eliminated, giving a relation between the propagating modes which may be of any number.

Since it is required that all the ports must be on the lateral boundary, devices such as the magic-T cannot be analyzed. Also, for computations to be simple, the heights of the connecting waveguides must be the same as the junction height.

Acknowledgment

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High-Efficiency Millimeter-Wave Bolometer Mount

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***Abstract*—A bolometer mount is described for measuring TE_{01}-mode waveguide power at a frequency of 100 GHz. This device is called an eight-fan-type bolometer mount. By dividing the electrode of the element into eight segments, the generation of an unwanted mode was suppressed, and, by minimizing the electrode area, heat loss due to the electrode was decreased.**

As a result, good matching characteristics and high effective efficiency were obtained. This mount is sufficiently useful for a precision power measurement in the millimeter-wave region.

Introduction

A BOLOMETER MOUNT is a standard device for measuring power at both centimeter and millimeter wavelengths. As the frequency increases in the millimeter-wave region, it becomes difficult to make a bolometer mount with good performances.

An effective efficiency [1] is obtained on bolometer mounts; effective efficiency is the ratio of the substituted bias power to the net RF power input to the bolometer mount. The effective efficiency generally degrades with increasing frequency in the millimeter wavelengths. This is so mainly because the millimeter-wave power dissipated in places other than the detecting element increases in the mount, and because the difference in the effectiveness of the millimeter-wave and the bias power in the element increases, owing to the expansion of the relative relation between the dimension of the bolometer element and that of the wavelength.

For instance, there is a commercially available thermistor mount having an efficiency of about 60 percent [2]. This efficiency is much lower than that of a conventional bolometer mount in the centimeter-wave region. A bolometer

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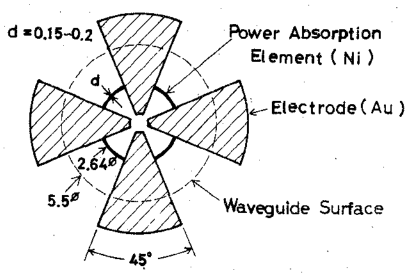

Fig. 1. Rising-sun-type bolometer element.

mount with low effective efficiency is undesirable for a precision power measurement, since the figure of the mount may vary with the power level to be measured.

With a view to improve this defect, the rising-sun-type bolometer mount [3], Fig. 1, was proposed. This is made of a circular TE_{01}-mode waveguide, the wall loss of which is lower than that of a rectangular waveguide. Though this mount fairly well attained the desired objective, several problems were left. The developed mount generates an unwanted higher mode (TE_{41}), and also the improvement in the effective efficiency is not satisfactory (about 70 percent).

In order to overcome these difficulties, a bolometer mount having an eight-fan-type electrode was made and examined, and good performances were obtained.

Eight-Fan-Type Bolometer Mount

The rising-sun-type bolometer element which is so designed as to be matched to the waveguide at 100 GHz is shown in Fig. 1. From this figure, the following properties of a mount with this element are known.

1) The rising-sun-type bolometer mount may generate the unwanted TE_{41} mode due to the four-segment electrode of the element.

2) Because the area of the electrode occupies about half the waveguide cross section, there is a large heat loss.

It is clear that these may be the main cause of the poorer effective efficiency of the mount. These facts lead to the ideas described below.

1) The bolometer element should have an eight-segment electrode, then it will not generate all unnecessary modes.

2) The area of the electrode of the element should be made as small as possible, then the heat loss of the electrode will be decreased.

To satisfy these conditions, at first, it is planned to subdivide the electrode of the rising-sun-type bolometer element into eight parts; simultaneously the angle of the electrode is to be made minimum. In the case where the element is fairly thin, TM modes are not generated, in principle, but TE modes may be generated. The circular waveguide used (5.5 mm diameter) can sustain five unwanted modes (TE_{11}, TE_{21}, TE_{31}, TE_{41}, TE_{12}) at a frequency of 100 GHz. But these modes are not generated in principle owing to the symmetrical structure of the eight-segment electrode.

Now it is rare to match the element described above to the waveguide because its impedance is too inductive. Therefore it is necessary to add susceptive components to the element.

Accordingly a bolometer mount for 100 GHz was

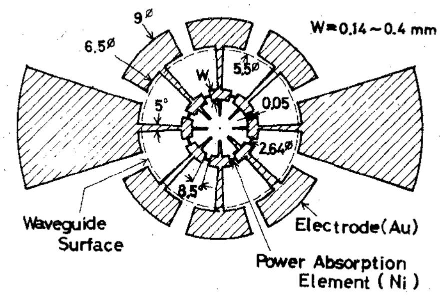

Fig. 2. Eight-fan-type bolometer element.

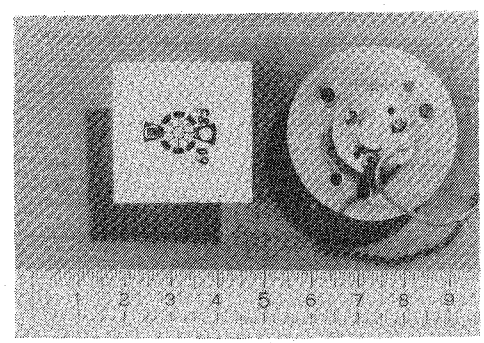

Fig. 3. Eight-fan-type bolometer element and mount.

designed as shown in Fig. 2, referring to the 35-GHz thin-film bolometer mount [4] as the prototype. This mount was named an eight-fan-type bolometer mount because of its shape. If the dimensions of each part of the element and the resistance of its power absorber are properly chosen, it will be matched to the waveguide by adjusting the position of a short circuit behind the element.

Several bolometer elements were made as follows. Au and Ni were deposited on a thin-film mica substrate (about 30 μm thick) as an electrode and a millimeter-wave power-absorption element, respectively. The width of the electrode W was selected to be 0.14, 0.3, and 0.4 mm. The working resistance R was chosen to be 100 and 200 Ω. The width of the Ni element was set to 0.05 mm.

These elements are terminated by fixed or sliding short circuits. Fig. 3 shows one of the elements and mounts for 100 GHz.

Experiments

The representative properties of the experimentally made bolometer elements are as follows: the cold resistance is 192 Ω; the sensitivity is 0.18 Ω/mW; and the bias power is 45 mW, which is applied to the large pair of electrodes.

When the impedance of the element is measured, one can easily find whether it is matched to the waveguide or not. The element will be matched when the impedance is on the reciprocal circle as shown in Fig. 4. That is, the impedance goes to the center point on the impedance chart along the reciprocal circle if the length of the short circuit behind the element is adjusted [3], [4].

The impedance measurement was accomplished at 100 GHz by a rectangular-TE_{10}/circular-TE_{01}-mode conversion-type reflectometer specially constructed for this purpose. The results are shown in Fig. 4.

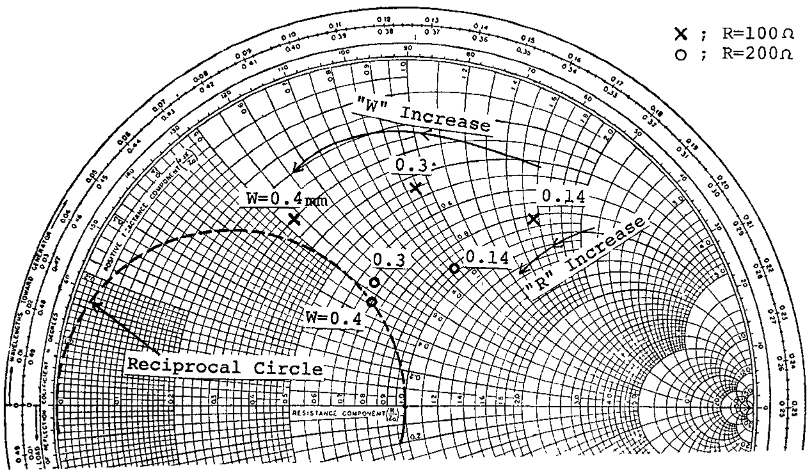

Fig. 4. Impedance characteristics of the bolometer element.

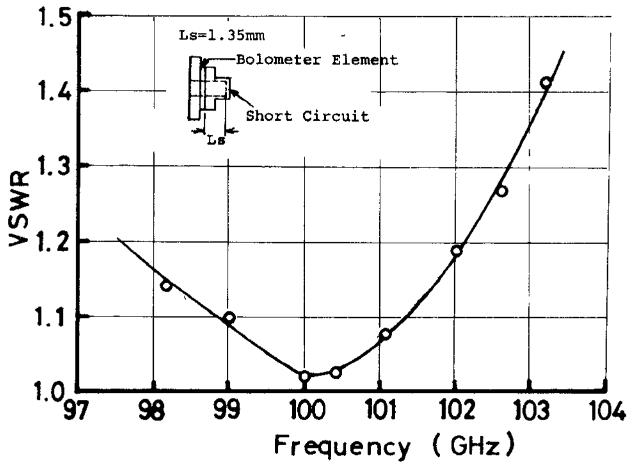

Fig. 5. VSWR versus frequency characteristics of the bolometer mount.

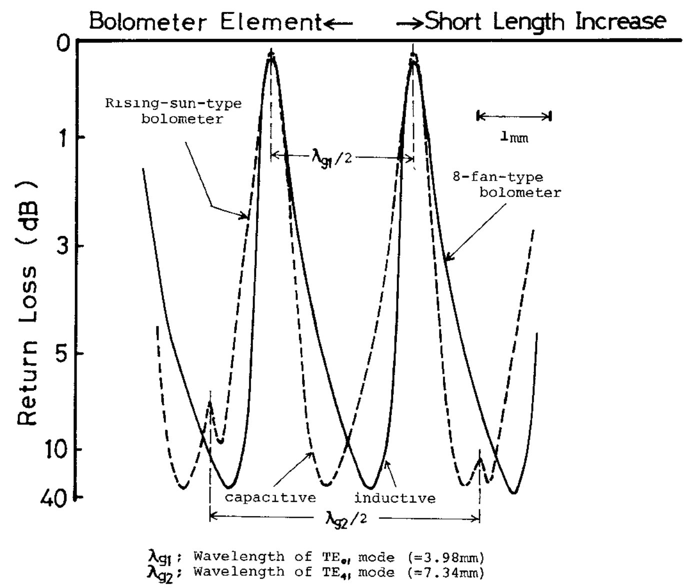

Fig. 6. Reflected wave pattern which is obtained by moving a sliding short circuit.

Fig. 4 shows that the element is inductive; its impedance approaches the capacitive side with increasing W and crosses the reciprocal circle at the proper electrode width. When W is 0.4 mm and R is 200 Ω, the element will be in matched condition.

The VSWR versus frequency characteristics of the mount which uses this element are shown in Fig. 5. The VSWR is less than 1.2 over a 4-GHz bandwidth at 100 GHz and nearly equal to that of the thermistor mount specified in [1]. This bandwidth is twice that of the rising-sun-type bolometer mount.

The effective efficiency of the mount was also measured using a Peltier cooling calorimeter [5] constructed for the circular waveguide at 100 GHz; an effective efficiency of 97 ± 1 percent was obtained at a power level of 10 mW. This value is much higher than that of the same frequency region and nearly equal to the value of a bolometer mount at 10 GHz.

Though the ideal eight-fan-type bolometer element should not generate any unwanted modes in principle, as already described, the actual element is not usually desired and may generate unwanted modes. This is experimentally verified by an investigation of the reflected wave pattern obtained by moving a sliding short circuit behind the element. If any unwanted modes are generated, the reflected wave pattern may have some variation such as a sharp dip. If only one unwanted mode exists, the following relation [6]–[8] holds:

$$\beta_u = \pi/L$$

where β_u is the phase constant of the unwanted mode and L is the dip-to-dip distance on the reflected wave pattern.

This is demonstrated, in Fig. 6, by comparison of the response of the present bolometer to that of the rising-sun type. The generation of a TE_{41} mode is clearly observed for the rising-sun-type bolometer mount, but is much less for the eight-fan-type bolometer mount. The smooth change of the curve shows that the generation of another unwanted mode may be very small.

Consequently the eight-fan-type bolometer mount has good matching characteristics and a high effective efficiency. This bolometer mount may also be useful for the power measurement of a rectangular-mode wave by using a suitable adaptor [9]. Further, the effective efficiency of a rectangular bolometer mount may be calibrated from this mount, using the comparison method with a directional coupler and an adaptor [9].

Conclusion

For a precise power measurement in the millimeter-wave region, an eight-fan-type bolometer mount was designed and tested at a frequency of 100 GHz. This mount has a very high effective efficiency compared to a conventional bolometer mount in the same frequency region. The proposed mount is not only useful for actual power measurement, but is also suitable for calibration of a power standard mount by a calorimeter because of its compact dimension and small heat capacity.

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Complex Permittivity of GaAs and CdTe at Microwave Frequencies

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***Abstract*—The microwave dielectric constant and loss tangent of Cr-doped semi-insulating GaAs have been measured in the frequency range 2.5–36.0 GHz and the temperature range 300–400 K. The room temperature dielectric constant is 12.95 and the temperature coefficient α ($\equiv \varepsilon(0)^{-1}\, d\varepsilon/dT$) is 1.6×10^{-4}/K. The dielectric constant and loss tangent of CdTe have been measured as functions of temperature at 15.95 GHz. The room temperature dielectric constant is 10.39 ± 0.04 and the temperature coefficient α is 2.5×10^{-4}/K.**

I. Introduction

The complex permittivity of Cr-doped semi-insulating GaAs at microwave frequencies is of interest both to microwave component designers and the solid-state physicist. In microwave integrated circuits using GaAs devices the material is both the substrate for the epitaxial layer and the microwave transmission medium in the form of a microstrip or slot line. For electrooptic modulation at microwave frequencies the dielectric constant is required for the design of the device and the matching structures, and knowledge of the loss tangent is needed to estimate the insertion loss. The effective mass of electrons and holes in a semiconducting material can be inferred from measurements of the dielectric constant as a function of temperature provided the properties of the lattice dielectric constant are known, i.e., the dielectric properties in the absence of charge carriers. The effective ionic charge can also be deduced from measurements of the "static" and optical dielectric constants.

The last decade has seen a large number of published results on the dielectric properties of GaAs, among them low-frequency capacitance measurements [1], [2], microwave measurements in the frequency range 2.0–70.2 GHz [3]–[11], and infrared transmission and reflection measurements [12]–[14]. The above experiments have produced values of relative dielectric constants which vary from 9.8 to 13.3. The temperature coefficient of the dielectric constant has been measured at low frequencies [2], and at 70.2 GHz [8], [9], while there are only two reported values of the loss tangent, one at 9.4 GHz [5] and one at 60 GHz [15].

In the case of CdTe, the only reported measurements of the dielectric constant are either low-frequency capacitance measurements [2], [16]–[18] or infrared measurements [19], except for Popa [15] who has reported a loss tangent measurement at 60 GHz.

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