AIP Review of Scientific Instruments

An improved coaxial coupler for measurement of the microwave Hall effect

A. Y. Al Zoubi, T. E. Cross, and D. A. Mohamed Isa

Citation: Review of Scientific Instruments **62**, 3089 (1991); doi: 10.1063/1.1142158
View online: http://dx.doi.org/10.1063/1.1142158
View Table of Contents: http://scitation.aip.org/content/aip/journal/rsi/62/12?ver=pdfcov
Published by the AIP Publishing

An improved coaxial coupler for measurement of the microwave Hall effect

A. Y. Al Zoubi,[a] T. E. Cross, and D. A. Mohamed Isa
Electrical Engineering Department, Nottingham University, University Park, Nottingham NG7 2RD, United Kingdom

(Received 28 January 1991; accepted for publication 20 August 1991)

The design and construction of a low-losses coaxial double-slug tuner for impedance matching of a bimodal cavity resonator is described. Voltage-standing-wave-ratio values close to one were readily achieved and significant improvements in the cavity Q factor have been realized using this new coupler. Accurate microwave Hall mobility results have been obtained and 60% reduction in experimental time was possible. A decrease in resistive losses in the order of 2 dB enhanced the measurement sensitivity and the lower bound of the detectable mobility was also reduced to 2.5 $cm^2/V\,s$.

I. INTRODUCTION

The use of a bimodal cavity in the measurement of the microwave Hall effect is a well-established technique.[1–3] The bimodal cavity supports two independent modes that have equal Q factors and resonate at the same frequency. The material under test in a magnetic field causes the two modes to couple resulting in a power transfer between the cavity input and output. This transfer of power gives a measure of the Hall mobility of the test sample.[4]

The electrodeless microwave method of measurement has proven to be a valuable tool in characterizing the electronic properties of high-resistivity and low-mobility materials.[5] This is particularly useful for biological, organic, and polymeric materials with physical properties that may preclude measurements by conventional means.

However, the microwave Hall-effect apparatus suffers from a number of limitations such as the empty cavity signal[6] and the losses incurred in the cavity coupling.[7] These limitations degrade the system measurement sensitivity and Q factor and place a lower limit in the minimum detectable Hall mobility. Methods of reducing the empty cavity signal have been developed that significantly enhance the measurement sensitivity.[7] However, further improvements in sensitivity may be obtained with the aid of an impedance matching slug tuner. The action of this tuner may result in a decrease in coupling losses and consequently improving the cavity-loaded Q factor.

In this paper, the design and construction of a double-slug tuner is described. Results on resistive losses and Q-factor measurements made on a bimodal cavity are presented. Hall mobility measurements on silicon and germanium are also reported and the accuracy of measurement is assessed.

II. SLUG TUNER DESIGN

Maximum power transfer from a microwave generator into a cavity resonator may be obtained using an impedance matching system that reduces the standing waves in the transmission line. The system must not have losses greater than that present in the transmission line in order to obtain significant improvements in the cavity-loaded Q factor. Consequently, critical coupling may not necessarily imply maximum power transfer from the generator to the cavity. However, critical coupling could be referred to as a transfer of power to the cavity via a slightly lossy line without the presence of standing waves in the line. This condition may be achieved using a double-slug tuner which consists of two dielectric disks housed in between the conductors of a coaxial air-articulated line. Each disk, commonly referred to as a slug, acts as a quarter-wavelength impedance transformer. The slug matches the line impedance to the load presented by the cavity at the input plane. This is achieved by introducing a counteracting voltage standing-wave ratio (VSWR) of a magnitude and phase proportional to the dielectric constant and the separation of the disks, respectively.

The slugs were made of PTFE of 5-mm thickness while the air-articulated coaxial cable in which the slugs were housed was made of 99.9% pure copper. The line was made one wavelength long to provide flexibility in the choice of slug thickness and also to enable the full range of adjustment of slug separation. The dimensions of the inner conductor diameter and outer conductor inside diameter were chosen to be 9 and 22.15 mm, respectively, in order to give a characteristic impedance of 50 Ω. The maximum power capability of the tuner was estimated at 200 W assuming a breakdown voltage in air of 3 MV/m.

The slug tuner was coupled to the microwave cavity via a probe made of a length of UT-85 semirigid microcoaxial cable as shown in Fig. 1. The generator end of the slug was fitted with a female SMA panel socket to facilitate mating with a UT-141 microcoaxial cable coupled to an SMA connector.

The capability of independently adjusting slug separation with respect to each other and the midpoint of the two slugs with respect to the load was obtained through an adjustment jig as shown in Fig. 1. This jig consisted of aluminium left- and right-hand screws that drove the two slugs apart (or together) while keeping their separation at the same position in the coaxial line. This arrangement was further mounted onto another adjustment jig that was clamped to the outer conductor of the air-articulated line as shown in Fig. 1. The complete jig was used to move the

[a]Now at Mutah University, Karak, Jordan.

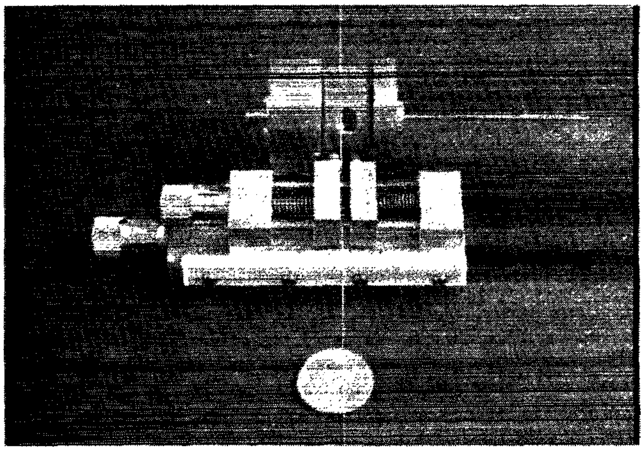

FIG. 1. The double-slug tuner incorporating the mounting jig, driving screws, UT-85 coaxial cable, and SMA connector.

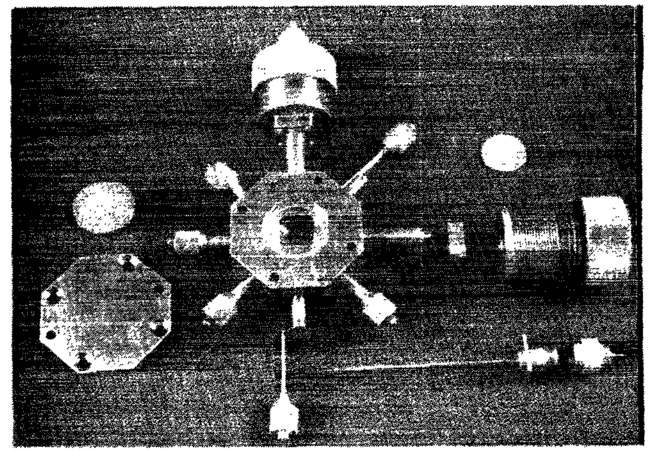

FIG. 2. The X-band cavity with tuning stubs, input and output probes, and the threaded insertion unit (bellows).

first setup over the whole length of the line thereby allowing variation in the position of the midpoint of the slug while keeping the same separation between them. The slot through which the slugs were driven from the external jig was cut parallel to current flow, i.e., along the axis of transmission. The slot width was 2 mm so that changes in the characteristic impedance of only 0.02% could be obtained.

III. RESULTS AND DISCUSSIONS

A microwave rectangular cavity operating at its fundamental modes with a resonant frequency of 9.6 GHz was utilized in the measurements of the Hall mobility on a variety of materials. The cavity resonated at the TE_{101} and TE_{011} degenerate modes such that the Hall effect in a sample placed at the center of the cavity caused the modes to couple when a static magnetic field was applied. This results in a Hall output power that is a measure of the Hall mobility value of the test sample. However, unavoidable machining errors in the cavity destroyed the degeneracy of the two modes and the condition of infinite decoupling between the input and output could not be achieved. The cavity was therefore provided with two resistive and four reactive tuning stubs at 45° intervals as shown in Fig. 2. These stubs were used to equate the resonant frequencies and Q factors of the two modes prior to Hall-effect measurements. Probe coupling was chosen to excite the cavity so that critical coupling could be obtained by adjusting probe insertion into the cavity using a threaded unit as shown in Fig. 2. This coupler, referred to as a bellows, was used in microwave Hall mobility measurements but proved too lossy and unreliable. Although critical coupling, the condition of maximum measurement sensitivity, was achieved using this coupler, its large resistive losses resulted in an undesirable reduction in the cavity Q factor. Furthermore the cavity must be tuned for orthogonality and degeneracy of the input and output modes using the tuning stubs. This procedure has proven to be extremely tedious and has to be undertaken using an iterative approach. Since a change in one mode could have an effect on the other as well as the condition of critical coupling, then the probe insertion and the tuning stubs must be readjusted until the cavity is effectively aligned. This process was repeated many times taking as long as 1 h for a single Hall mobility measurement.

By replacing both input and output bellows with double-slug tuners it was possible to improve the cavity Q factor. Three methods of measurements were used in determining the Q factor at different probe insertions implementing both bellows and slug tuners as shown in Fig. 3. Improvements of five orders of magnitude in Q were obtained using the slug tuner when compared to the bellows. The maximum value of Q, which corresponds to the critical coupling condition, was obtained at 2 mm probe insertion. For an insertion of 1 mm, Q was relatively low for both systems. This seems to indicate that a higher portion of power was dissipated in the coupling system. At probe insertions greater than 2 mm, Q decreases, which may be attributed to an increase in resistive losses as the probe intrudes into the cavity. The resistive losses R_s of both couplers were subsequently obtained from a Smith chart plot of the input impedance at various probe insertions as

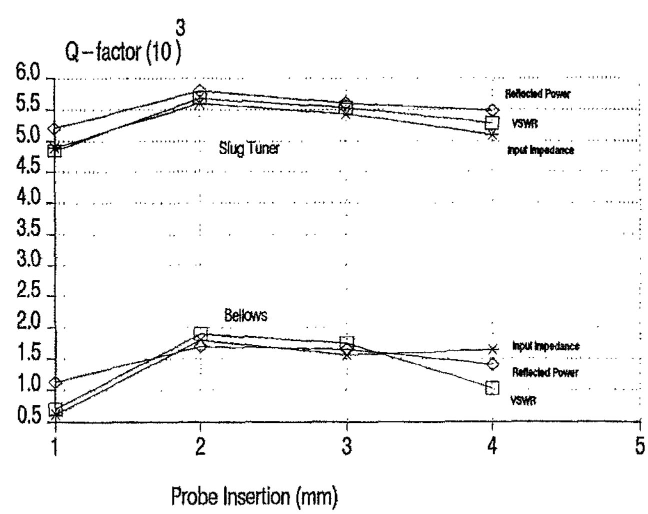

FIG. 3. The cavity Q factor measured at different probe insertions.

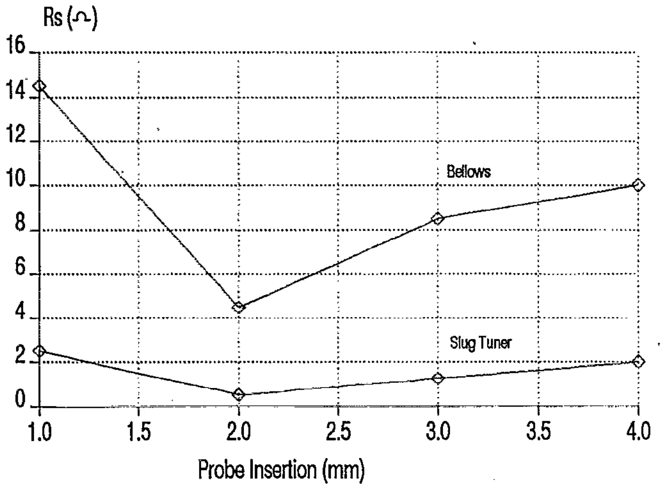

FIG. 4. Resistive losses R_s at different probe insertions.

shown in Fig. 4. Minimum losses occurred at 2 mm insertion at which the Q was maximum. This corresponds to the condition of critical coupling which could be achieved using both couplers. However, the slug tuner offers superior performance over the bellows since the losses incurred using the slug were minimal. The overall measurement time was also cut by 60% due to the ease in obtaining an impedance match. The slug tuner also aided in balancing the cavity before the sample was inserted thereby allowing extra control in aligning and equating the cavity modes.

Measurements on the Hall mobility have initially been made on a number of semiconductors using the bellows. The dc and microwave Hall mobility values were compared and the constant of proportionality equating them gave a measure of the total system losses which were estimated at 4 dB. Subsequent measurements assumed this value of losses to be constant,[7] a procedure that has been proven inaccurate and may result in errors as large as 60% as shown in Table I. Each measurement was performed using two samples of sizes 1×1 mm and 2×2 mm with a nominal thickness of 500 μm. The values of the microwave Hall mobility given in the table assumed system losses estimated at 4 dB and the percentage error in the mobility value is given relative to the dc one.

The use of the slug tuner increased the measurement sensitivity by 2 dB as losses incurred in the dielectric slug were minimized. This can be shown in Table II where the dc and microwave Hall mobilities are compared for a number of samples giving a maximum error of only 5%. These measurements were also obtained without the need to calibrate the results since the constant probe insertion indicated that losses remain relatively constant for all measurements, thereby increasing the chances of reproducible results. As the system sensitivity increased by 2 dB, the minimum detectable Hall mobility at 1 T was also reduced from 3.2 to 2.5 cm^2/V s for a cavity with aluminium end walls.

TABLE I. A comparison of dc and microwave Hall mobility values with percentage error. All mobility values are in cm^2/V s.

Material	dc mobility	Microwave mobility	% error
p-Ge	2600	2452	5.7
		2271	12.6
p-Si	650	447	31.2
		396	39
p-Si	200	195	2.5
		174	12.8
n-Si	850	539	36.6
		529	37.7
n-GaAs	3200	1268	60.4

TABLE II. A comparison of dc and microwave Hall mobility values obtained using slug tuners. All mobility values are given in cm^2/V s.

Material	dc mobility	Microwave mobility	% error
p-Ge	2600	2567	1.3
		2590	0.4
p-Si	200	197	1.5
		190	5.0
n-Si	850	843	0.8
		840	1.2

Further measurements have been made on copper phthalocyanine (CuPc) using the double-slug tuners and a hybrid cavity.[3] This needle-shaped material exhibits extremely high resistivity ranging from 10^{12} to 10^{13} Ω cm at room temperature. A p-type mobility value of the order 38 ± 5 cm^2/V s was measured which is in agreement with that reported by Caverly and Westgate but the observed polarity is in contrast to their reported n-type polarity.[5]

The application of the versatile double-slug tuner makes the Hall spectrometer a truly wide-band measurement apparatus since microcoaxial cables can be used to replace waveguides. Cavities of different frequencies may be employed in the investigation of the electronic properties in a variety of materials. The Hall-effect apparatus may also be extended to include permittivity, conductivity, and electron-spin-resonance measurements particularly in biological, organic and polymeric substances.

ACKNOWLEDGMENTS

The authors would like to acknowledge the meticulous skills of Mr. B. Robinson in fabricating the slug tuner and Mr. K. White in fabricating the cavity, Miss N. Baba-Ali for her assistance in making Ohmic contacts on the samples, and Mrs. D. Anderson of WACKER Chemitronic division for generously providing some of the samples. The financial support of the National University of Malysia to D.A.M.I. is deeply appreciated.

[1] D. D. Eley and N. C. Lockhart, J. Phys. E., **16**, 47 (1983).
[2] R. Pethig and R. South, IEEE Trans. Instrum. Meas. **IM-23**, 460 (1974).
[3] T. E. Cross, D. de Gogan, and A. Y. Al Zoubi, Institute of Physics Conference, Series No. 89, Session 8, 31, 22–25 September, 1987, Warwick, United Kingdom.
[4] M. Sayed and C. Westgate, Rev. Sci. Instrum. **46**, 1074 (1975).
[5] R. Caverly and C. Westgate, J. Appl. Phys. **53**, 7410 (1982).
[6] A. Y. Al Zoubi, IEE Proc. **137**, 78 (1990).
[7] A. Y. Al Zoubi, Ph. D. thesis, Nottingham University, 1987.