HIGH BURNOUT GALLIUM ARSENIDE SCHOTTKY BARRIER DIODES

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Abstract

This paper discusses the results of a programme to investigate the burnout phenomena of gallium arsenide Schottky barrier mixer diodes with regard to radar system t.r. cell leakage, and describes the performance of X-band high burnout diodes.

Introduction

Microwave receiver reliability is largely dependent on the burnout properties of the diode effecting frequency changing or detection of microwave pulses. The design of point contact diodes to improve their capability as regards resistance to electrical overloads, has been fully exploited. However with the advent of Schottky barrier diode and its associated large contact area when compared with point contact technology, a significant improvement in resistance to burnout was theoretically expected. Practical experience however with transmit-receive radar systems, where the mixer diode is protected by a t.r. cell, soon indicated that the burnout capability of the Schottky barrier diode was not necessarily better than the point contact type.

It was against this background that studies of the burnout of planar microwave diodes were undertaken. The objective being to obtain a better understanding of the burnout mechanism and to realise the potential high burnout and low noise figure capability of these devices. This would lead to high performance reliable microwave receivers for transmit-receive radar applications.

Diode Burnout

Mixer diode burnout as the result of t.r. cell spike leakage, is a special case of diode failure caused by an excessive electrical over load. The significance is that in this case the t.r. cell leakage spike width is normally shorter than the thermal time constant of the mixer diode, with the result that the time is too short for heat to be appreciably conducted away during the duration of the spike from the locality where it was generated. Thus, although diode degradation may still be attributed to high temperatures occurring at the metal-semiconductor interface, resulting in diffusion, alloying or melting, it is believed that this is aggravated by severe temperature edge effects. Short spike considerations also lead to mixer diode burnout being specified in terms of spike energy t.r. cell leakage, rather than peak pulse power[1].

Diode Structure

Because of the high electron mobility of gallium arsenide, compared with say silicon or germanium, this material has the best performance potential at microwave frequencies and was consequently chosen as the semiconductor material for this study. Schottky barrier diodes have been fabricated using epitaxial gallium arsenide in the L.I.D. structure to allow incorporation of a bonded contact[2]. The use of wire pressure contacts to the Schottky rectifying junction has thus been avoided. The diodes have employed barrier contacts of about 10 µm diameter with a gold overlay of about 15 µm diameter to facilitate thermocompression bonding of the gold contact wire. For microwave testing, these devices have been introduced into the X-band 1N23 encapsulation as shown in Fig.1, and r.f.matched into a 1N23 test mount. Only devices with a v.s.w.r. <1.5:1 and an overall noise figure performance <6.5 dB (F.i.f. 1.5 dB) have been accepted for burnout tests. Burnout evaluation has been carried out using calibrated X-band t.r. cells to provide information which is directly applicable to practical systems. D.C. spike tests have not been used so as to avoid anomalous results. A diode has been assumed to be burnt out when its noise figure performance has deteriorated by 1dB or greater.

Burnout Studies

Studies have been carried out into the use of different barrier metals, effect of orientation (<111> and <100>) of the gallium arsenide material and the effect of different contact geometries. To obtain a better understanding of the burnout mechanism, scanning electron microscope and X-ray topographical techniques have been employed to examine the diode junction both before and after diode burnout.

Initial results of these studies are briefly summarised below.

Examination of different barrier metals has indicated that low noise figure (i.e. 5.2 to 6.5 dB) mixer diodes may be produced using gold, titanium, nickel, molybdenum and rhodium contacts. The use of nickel has resulted in diodes exhibiting the best burnout resistance. Safe t.r. cell leakage levels of about 0.5 e/s have been established for several hundreds of hours, and a level of up to 1.0 e/s has been observed. Inferior levels of about 0.1 to 0.2 e/s were exhibited by gold and titanium.

Examination of diodes produced on <111> and <100> gallium arsenide orientated materials, using nickel as the contact metal, has demonstrated the superiority of the <111> material when processed in the same manner. A direct comparison gives a burnout level of > 0.5 e/s for the <111> orientation, compared with about 0.25 e/s for the <100> orientation.

Theoretically, the contact geometry should have a marked effect on the diode burnout performance, when considering t.r. cell leakage spikes which are shorter than the thermal time constant of the diode. However examination of line contacts compared with conventional circular contacts have at this time not shown any significant difference in

Table I

	% Survival (1)					Noise Figure F.i.f. 1.5dB	Diode (2) Exponent
	0.12 e/s	0.25 e/s	0.5 e/s	0.75 e/s	1.0 e/s	dB	'n' Value
Gold/GaAs (111)	100	60	30	0		5.3 to 6.5	1.10
Titanium/GaAs (111)	50	15	0			5.2 to 6.5	1.12
Molybdenum/GaAs (111)	100	60	35	0		5.6 to 6.5	1.15
Rhodium/GaAs (100)	100	100	50	20	0	5.8 to 6.5	1.13
Nickel/GaAs (100)	100	80	50	10	0	5.5 to 6.5	1.06
Nickel/GaAs (111)	100	100	80	35	10	5.2 to 6.0	1.05
Silicon Point Contact	100	80	0				1.50

(1) Energy levels obtained from calibrated t.r. cells. Duration of test = 10 mins
Criterion for failure : 1 dB or more change in noise figure.
(2) Diode exponent 'n' derived from diode I-V characteristic of the form:

$$I = I_s \left[\left(\exp \frac{eV}{nKT} \right) - 1 \right] . \quad n = 1.0 \text{ for ideal characteristic.}$$

burnout characteristics.

Burnout Results

Typical burnout results and diode characteristics are summarised in Table I and typical dynamic noise figure performance as a function of t.r. cell spike leakage is illustrated in Fig.2. These not only indicate the dependency of burnout level on the diode technology, but also show that the gallium arsenide Schottky barrier diode does not exhibit any temporary deterioration effects. For the dynamic test the t.r. cell spike width was about 2 ns, and the peak power about 40 watts for the maximum available energy level of 0.68 e/s.

Results of tests using r.f. spikes of about 8 ns width, derived from a magnetron by a pulse cancellation technique, indicated a burnout level of about 2.5 e/s, peak power about 20 watts, for diodes surviving the 2 ns 0.68 e/s t.r. cell level.

S.E.M. Studies

The results of examination of the burnt out diode junctions by scanning electron microscope techniques, have indicated that there is no optical evidence associated with a device which has failed by slow degradation, but inspection of instantaneous failures, which normally result in an o/c, often show that the junction has erupted due to dissociation of the semiconductor. An example of a diode which has failed catastrophically is illustrated by the photographs of Fig.3. It is suggested that the mechanism of the slow failure, usually resulting in a s/c, may be due to the progressive diffusion of metal along dislocations or other available defects, to penetrate the epitaxial layer to the substrate material. Examination of this aspect by X-ray topographical techniques is being carried out.

Conclusions

The results of this study to date, have indicated the feasibility of producing low noise figure (<6.0 dB for F.i.f.= 1.5 dB) X-band gallium arsenide Schottky barrier diodes, which will withstand t.r. cell leakage levels in excess of 0.5 e/s and exhibit no temporary deterioration effects. It is envisaged that further studies will increase this level to about 1.0 e/s. This can be directly compared with burnout levels of about 0.2 e/s and noise figure performance of >7.0 dB for present point contact technology.

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References

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2. Oxley, T.H., Summers, J. and Hansom, A. 'The Development of Gallium Arsenide Schottky Barrier Diodes as Mixers and Detectors', I.E.E. European Microwave Conference, London, Sept. 1969.

Note: Eventual commercial exploitation, if any, of devices or components covered by this paper, will be undertaken by A.E.I. Semiconductors Ltd., Lincoln, England.

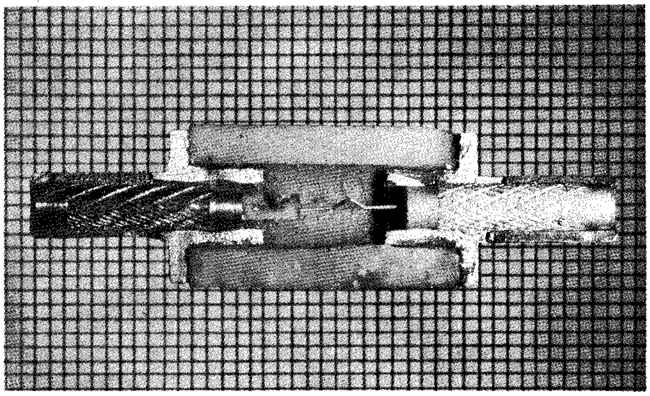
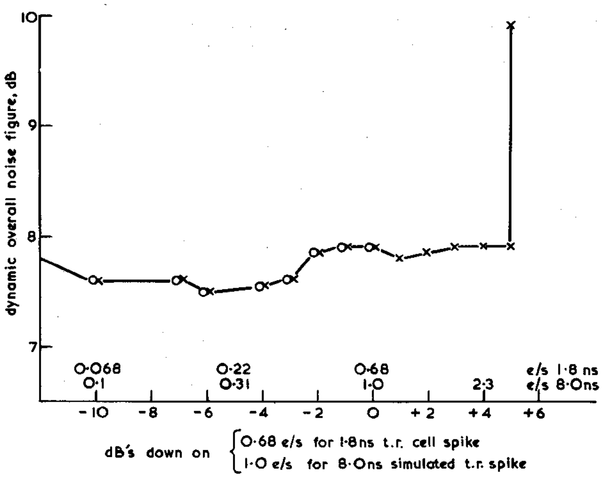


Fig.1 L.I.D. encapsulated in 1N23 outline



Typical Ni/GaAs <111> diode
Dynamic overall noise figure as a function of spike energy

One minute exposure tests to alternate short (1.8 ns) and long (8.0 ns) spikes.
Highest available short spike energy = 0.68 e/s
O = 1.8 ns spike X = 8.0 ns spike

Fig. 2 Summary of diode burnout performance

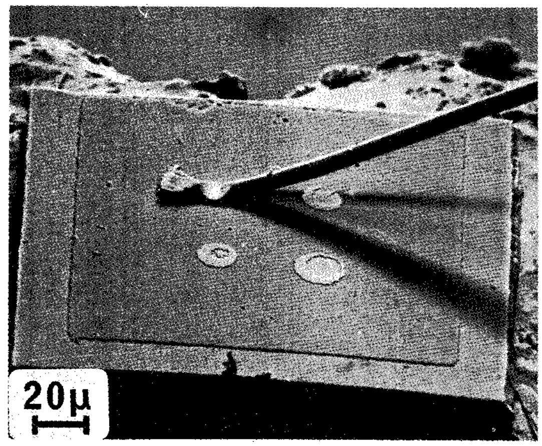


Fig. 3(a) Example of Schottky barrier wire bonded contact before burnout

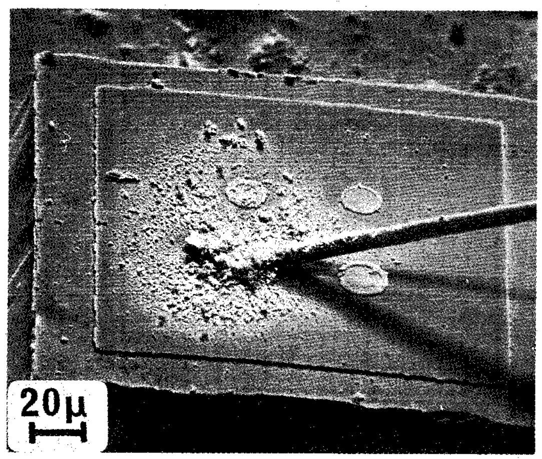


Fig. 3(b) Example of Schottky barrier wire bonded contact after catastrophic burnout

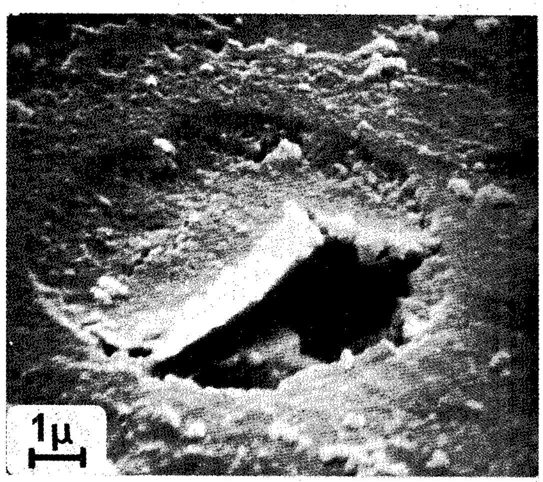


Fig. 3(c) Example of effect on metal-semiconductor Schottky barrier junction after catastrophic burnout. (Bonded contact wire and gold overlay removed by chemical etching)