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Proposed Model for Degradation of Gunn Diodes as Observed from Study of the I-V Characteristics

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Abstract. The effect of heat treatment on the functional Gunn diodes has been investigated in the temperature range of 200-300°C. The influence of electric field during heat treatment has also been studied. The simple variations in I-V characteristics with annealing time have been utilized to interpret the contact behaviour.

1. Introduction

Although numerous studies to investigate the behaviour of alloyed ohmic contacts of *GaAs* have been reported in literature[1-4], very scanty information is available regarding the effects of prolonged annealing on various functional *GaAs* based devices. The latter type of information is, however, very useful for an understanding of the reliability and long term stability of the devices. Apart from this, a number of *GaAs* based devices (e. g. Gunn diodes) get heated up to temperature 200-300°C during continuous operations, and therefore, the effects of prolonged heating on the performance of such devices become very important. The analysis of annealing in these cases, however, is very complex not only because of the involvement of a number of constituents in the formation of ohmic contacts but also due to the material band structure and the 'hot electron' effects associated with it.

The ohmic contact normally used for *GaAs* devices consists of a heavily doped layer of *GaAs* followed by metallization. Amongst the various combinations used for metallization, evaporated *AuGe* eutectic (88% *Au*, 12% *Ge*) followed by a thin layer of *Ni* and an overlayer of gold (alloyed at a temperature greater than the eutectic melting temperature) is most widely used for ohmic contacts[5,6] to n-*GaAs*. Micro-segregation effects, compositional variations in the vicinity of different interfaces, surface topography, etc., have been studied by various workers using AES, Rutherford scattering, SIMS, SEM, X-ray diffraction and optical microscopy. It has been observed that after alloying, *AuGe* eutectic, responsible for good ohmic contact, is interspersed in the *Au* or *Au* based matrices. In fact, the specific contact resistance has been found to be strongly dependent on the grain size of the *AuGe* eutectic[4] and has also been observed to increase by 20-25% after annealing at 250°C for about 150 hrs[7]. Some of the reasons for various types of lateral non-uniformities observed at the *GaAs* interface could be due to incomplete reaction and/or solid phase formation.

2. Experimental

In the present investigations, the functional Gunn diodes were subjected to prolonged heat treatment without and with electric field in the temperature range of 200-300°C and room temperature I-V measurements at different stages of annealing were utilized to interpret their contact behaviour.

The Gunn diodes, used for these investigations were fabricated in the laboratory[6]. Some diodes obtained from abroad for the sake of comparison were also used. The I-V characteristics of the encapsulated diodes, mounted on suitable heat sink, were

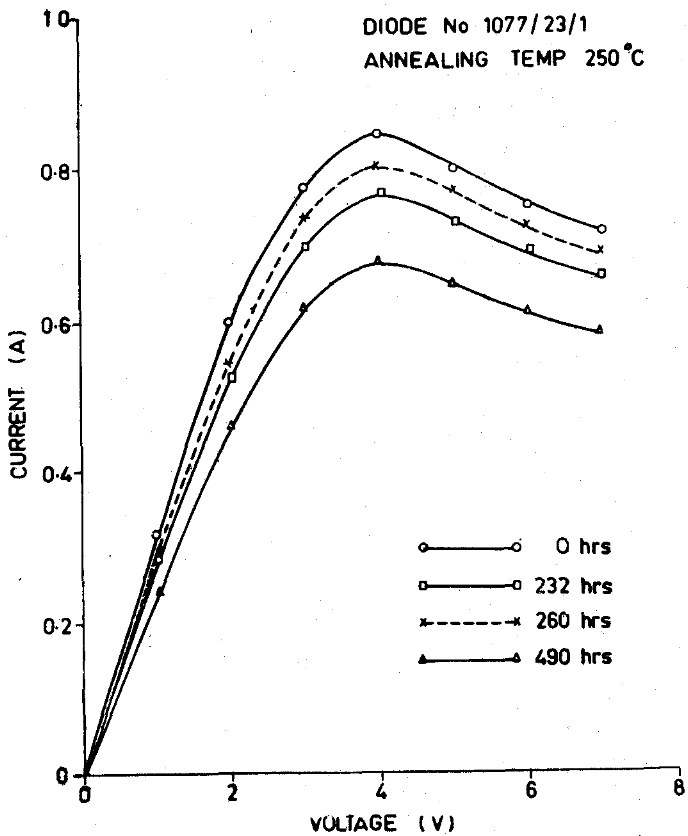

Figure 1. Room temperature I-V characteristics variation with annealing time.

measured prior to heat treatment. The diodes were subjected to thermal annealing at fixed temperatures (200°C, 250°C & 300°C) by placing them in an oven having air atmosphere. After removing the diodes from the oven and cooling them to room temperature their characteristics were measured at regular intervals of annealing. The typical room temperature variation in the I-V characteristics with annealing time for 250°C annealing are shown in Fig. 1.

The experiments were also carried out by applying fixed voltages (below the threshold limit) across the diodes during heat treatment. Both type of biasing (i.e epi-side biased negative and biased positive) were applied during annealing. The typical room temperature variations in the I-V characteristics with annealing time for 250°C annealing with epi-side biased negative and positive are shown in Figs. 2 and 3 respectively.

3. Results and Discussion

The experimental data on various diodes, annealed at different temperatures, qualitatively showed similar variations in the I-V characteristics with annealing time. As a typical example for discussion, the data of heat treatment at 250°C without and with electric field are used for interpretation. In the case of heat treatment

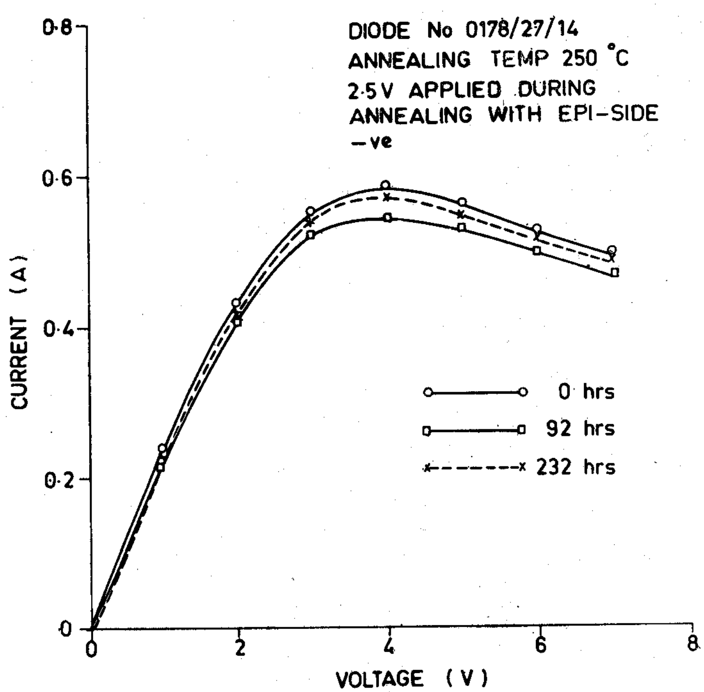

Figure 2. Room temperature I-V characteristics variation with annealing time for annealing with epi-side biased negative.

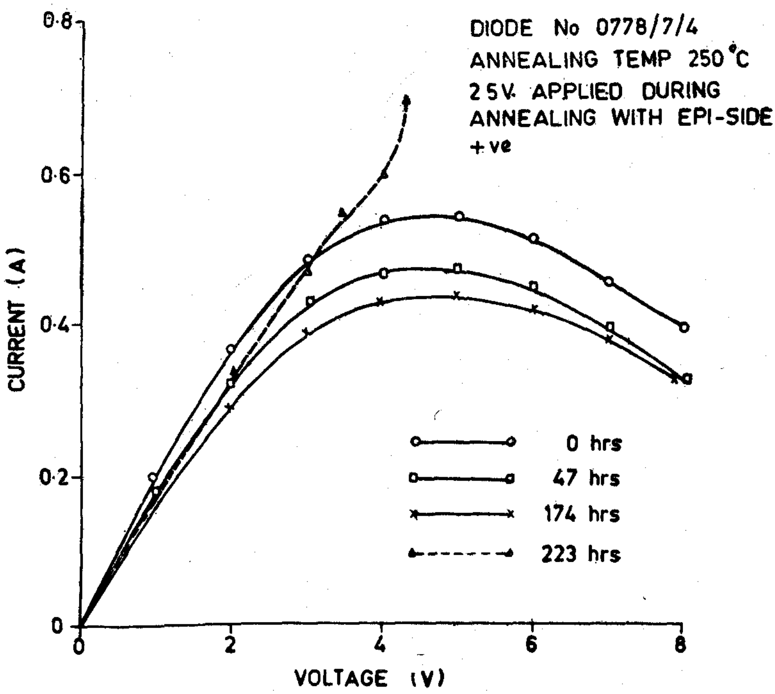

Figure 3. Room temperature I-V characteristics variations with annealing time for annealing with epi-side biased positive.

without electric field the current in the entire voltage range showed a decrease after cumulative annealing of about 50-60 hrs and continued to register further decrease up to 230 hrs. From the fall in the peak current at the threshold by annealing it can be concluded that not only the main active epitaxial layer is not affected to any appreciable extent, the specific contact resistance is also not very much altered. The decrease in peak current is indicative of a reduction in the effective contact area of the diode rather than increase in contact resistance, as the latter will only amount to a shift in the threshold position. In the absence of the availability of any non-destructive technique for evaluation of interfaces in functional devices, it is proposed that this decrease in the effective contact area is due to the penetration of *Ni* into the interspersed *AuGe* eutectic grains. After a period of 230 hrs further annealing leads to an intermediate period ($\sim$30 hrs) of increasing current before following a continuous downward trend (Fig. 1). This intermediate increase can be attributed to the predominance of leaky Schottky injection from non-ohmic region of the contact and/or possibly a lateral diffusion of *Ge* from the ohmic regions leading to a small increase in the effective contact area. The final decrease in current is primarily due to the diffusion of *Ni* into the buffer layer and formation of compensated regions around effective contact area. Mizuishi, *et al*[8] have also reported diffusion of *Ni*, in similar heat treatment conditions, responsible for degradation in contact resistance.

In view of the proposed model, in the case of annealing with epi-side biased negative, the migration of Nickel is arrested to a very large extent and currents are confined within tolerable limits even after annealing up to about 500 hrs. (Fig. 2). When epi-side is biased positive, the penetration of *Ni* is greatly enhanced causing continuous decrease in current and finally leading to catastrophic failure (Fig. 3). It must, however, be noted that a minimum applied voltage of about 2.5 V with epi-side biased negative is required to arrest this type of degradation in I-V characteristics at 250°C. This also explains several thousand hours of Gunn diode CW operations without failure even at 250-300°C active region temperatures.

On the basis of the above proposed model, it can be concluded that annealing brings about changes in the effective contact area rather than the changes in specific contact resistance values as envisaged by some earlier workers.

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