

Letters

A new mesa-etching technique for gallium arsenide

Gallium arsenide is now widely used to make microwave devices like Gunn diode, avalanche diode etc. A mesa configuration is very often used in many of the devices so that the device can be bonded face down to the heat sink to facilitate efficient heat transfer from the active region. To avoid problems associated with the formation of undesirable Schottky barriers arising from any contact between the bulk semiconductor and the heat sink, a deep mesa is desirable. With most of the conventional etchants, however, there is usually considerable under-cutting of the mesa which results in a deterioration of the device. A potassium cyanide, water and peroxide etch [1] has recently been proposed which gives good preferential etching. We have, however, found that this gives rather a rough surface and does not avoid undercutting for such deep mesas. We have discovered that the surface photovoltaic effect can be very suitably used for obtaining preferential etching in gallium arsenide. It is well known [2] that the etching rate of a semiconductor in an electrolytic solution can be considerably enhanced by shining light on the semiconductor-electrolyte interface. Thus if one has illuminated and dark regions on a semiconductor surface put in an electrolytic solution, the etching rate would be much larger in the illuminated areas. This property has been made use of in the fabrication of Gunn diodes. An array of circular metal contacts was deposited on an n on n⁺ GaAs wafer by evaporating Au-Ge-Ni [3] through a metal mask. The contacts were next alloyed at 450°C in a hydrogen atmosphere. The wafer was then placed in a 10 H₂SO₄:1 H₂O₂:1 H₂O solution on which light from a tungsten

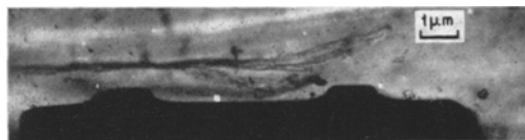


Figure 1 Transmitted light photograph of the section of a typical etched sample showing two mesas. Note the outward slope of the edge of the mesas.

filament lamp was incident. The metal dots protected the area underneath from illumination. The area uncovered was therefore etched without any undercutting giving rise to beautiful mesa-structures. A typical sample is potted in a transparent resin and Fig. 1 shows the photograph of the section of two mesa-structures taken in transmitted light. One can note the absence of undercutting at the edges of the mesas. Diodes are now being made routinely using this technique dissipating typically 10 W of power without any degradation of the device. This technique can also be suitably used for making mesa on other devices.

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Stress relaxation in superplastic materials

The stress relaxation technique has been extensively utilized in the recent past to study the plastic flow in crystalline solids [1-9]. In this method, a specimen is deformed, at a given temperature, to some stress level. The machine crosshead is then arrested and subsequent load

drop, which occurs by the plastic flow of the specimen relieving elastic strain of specimen and machine, is recorded as a function of time. From the analysis of load relaxation curves, it is possible to determine the dislocation velocity – stress exponent, thermal and athermal components of flow stress and various thermodynamic parameters associated with plastic deformation such as activation energy and activation volume.

An advantage of this technique is that it represents a considerable short-cut from the more conventional methods of mechanical testing. The purpose of the present communication is to point out and demonstrate the applicability of the stress relaxation technique to superplastic materials with certain advantages.

The mode in which the relaxation test is especially convenient in studying superplastic behaviour is presented below.

1. In a stress relaxation test, the rate of relaxation of stress ($\dot{\sigma}$) is proportional to the plastic strain-rate ($\dot{\epsilon}_p$) [4].

$$\dot{\epsilon}_p = - M \dot{\sigma} \quad (1)$$

where

$$M = \left[\frac{1}{E} + \frac{A}{LS} \right].$$

Here, E is the Young's modulus of the specimen, A and L are the cross-sectional area and gauge length of the specimen, respectively, at the beginning of the relaxation test and S is the stiffness of the machine ($S = P/X_M$, where P is load and X_M is the corresponding elastic displacement of different parts of the machine). Initially when the specimen is still in its elastic range, we have

$$X = X_e + X_M \quad (2)$$

where X is displacement of the crosshead and X_e is elastic extension of specimen. Substituting for X_e and X_M in terms of load, specimen dimensions and elastic moduli, in Equation 2 we obtain

$$X = \frac{PL}{AE} + \frac{P}{S}$$

or

$$\frac{X}{L\sigma} = \left(\frac{1}{E} + \frac{A}{LS} \right) = M. \quad (3)$$

It is obvious that M decreases with increasing tensile plastic strain. If stress relaxation tests are to be conducted at different plastic strains, it is necessary to evaluate M at each plastic strain. The value of M at higher plastic strains can also be calculated from its initial value at zero plastic strain using the Young's modulus of the specimen or the stiffness of the machine. Knowing M and using Equation 1 it is then possible to determine the stress-strain rate data from the stress relaxation curve. A single stress relaxation test yields stress-strain rate data over a wide range of strain-rates [9] and especially at low strain-rates which can normally be attained in

creep tests but not in Instron tests. These data would be of significance in characterizing the superplastic behaviour where flow stress is strongly strain-rate sensitive.

A question relating to the strongly viscous characteristic of superplastic deformation is whether there is any finite yield (Bingham) stress below which no permanent deformation is possible. The presence of such a Bingham yield stress can be detected as that at which the stress relaxation rate is zero in a relaxation test. This method has already been applied to determine the Bingham stress in a Mg alloy [10].

2. The nature of stress-strain rate relation in superplastic materials can be obtained in an alternative way without directly evaluating these quantities from the relaxation curve. We can assume a possible stress-strain rate relation and then verify whether this is consistent with the observed relaxation curve. This procedure is illustrated below in two simple cases.

(a) Let the stress (σ)–strain-rate ($\dot{\epsilon}_p$) relation be of the empirical form

$$\sigma = K \dot{\epsilon}_p^m \quad (4)$$

at a given temperature, where K is a constant and m is known as the strain-rate sensitivity index. We further treat the simplest case, in which m is not a function of strain-rate over some strain-rate ranges. This behaviour is analogous to steady state creep and it implies that there is no Bingham yield stress. From Equation 4

$$\dot{\epsilon}_p = K_1 \sigma^n \quad (5)$$

where $K_1 = (1/K)^{1/m}$ and $n = 1/m$.

Substituting Equation 5 into 1, we obtain

$$K_1 \sigma^n = - M \dot{\sigma}$$

or

$$-\sigma^{-n} d\sigma = K_2 dt \quad (6)$$

where $K_2 = K_1/M$. Integrating Equation 6 under the assumption of constant n and K_2 , and Rewriting it we obtain

$$\sigma^{1-n} = K_3(t + a)$$

where $K_3 = K_2(n - 1)$ and a is an integrating constant.

Taking logarithms,

$$(1 - n) \ln \sigma = \ln K_3 + \ln(t + a)$$

or

$$\ln \sigma = K_4 + \frac{1}{(1 - n)} \ln(t + a) \quad (7)$$

where $K_4 = \ln K_3/(1 - n)$. Thus, plotting $\ln \sigma$ against $\ln t$ should yield a straight line of

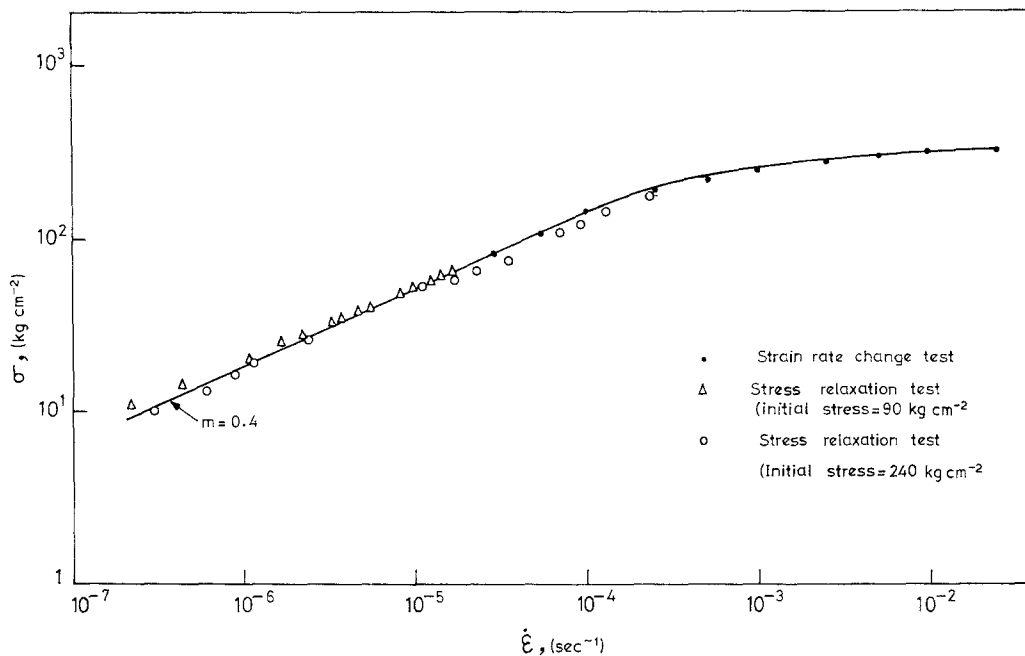


Figure 1 Stress-strain rate data of Sn-Pb eutectic alloy at 30°C obtained by differential strain-rate and stress relaxation techniques.

slope $1/(1-n)$ when $t \gg a$.

(b) If a Bingham yield stress (σ_B) is present in the above representation, then

$$\sigma = \sigma_B + K \dot{\epsilon}_p^m$$

or

$$\dot{\epsilon}_p = K_1(\sigma - \sigma_B)^n$$

where

$$K_1 = \left(\frac{1}{K}\right)^{1/m} \text{ and } n = 1/m.$$

Hence

$$\dot{\epsilon}_p = -M\dot{\sigma} = K_1(\sigma - \sigma_B)^n$$

or

$$-(\sigma - \sigma_B)^{-n} d\sigma = \frac{K_1}{M} dt.$$

Integrating under the assumption of constant σ_B , n and K_1/M ,

$$(\sigma - \sigma_B)^{1-n} = K_2(t + a)$$

where $K_2 = (n-1)K_1/M$ and a is an integrating constant or

$$(\sigma - \sigma_B) = K_3(t + a)^{-n_1} \quad (8)$$

where $K_3 = K_2^{1/(1-n)}$ and $n_1 = 1/(n-1)$. From this, it follows that a log-log plot of stress-rate versus time should be linear when $t \gg a$. The value of m can be determined from its slope. σ_B

can also be estimated from the relaxation curve without establishing the condition of zero relaxation rate. This procedure is analogous to that of Gupta and Li [11] in evaluating the internal stress in a work hardened material.

The applicability of the stress relaxation technique was studied on a superplastic Sn-Pb eutectic alloy. All the tests were done in tension on an Instron machine at room temperature (30°C). The stress-strain rate data were collected by the differential strain-rate method [12] and shown in Fig. 1. The strain-rate sensitivity index was about 0.4 at low strain-rates and it decreased with increasing strain-rate. Stress relaxation tests were carried out on the same specimen at two different initial stresses. Instron chart speeds up to 50 cm min⁻¹ were used in order to increase the precision in slope measurement of the relaxation curve. The relaxation curves were monitored up to about 10 min and the condition of zero relaxation rate was not attained in this period. The slopes of the relaxation curves were determined graphically at different points. The stress-strain rate data obtained from the stress relaxation test are also shown in Fig. 1. The data obtained by the two methods agree reasonably in the overlapping range between them. The strain-rate sensitivity index was observed to remain

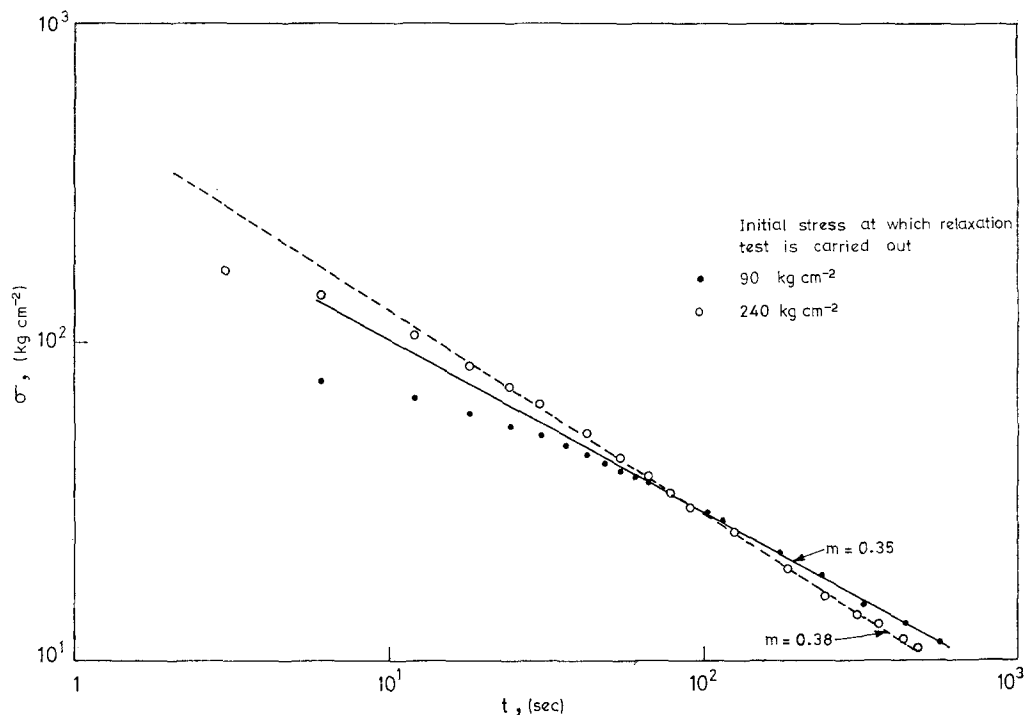


Figure 2 Log-log plot of stress against time in the stress relaxation of Sn-Pb eutectic alloy at 30°C.

constant at 0.4 down to the lowest strain-rate ($\sim 10^{-7} \text{ sec}^{-1}$), attained in the stress relaxation test. The stress relaxation curves were further analysed in terms of Equations 7 and 8. While a log-log plot of stress-rate versus time was observed to be non-linear throughout, the log-log plot of stress against time was linear at longer times (Fig. 2). From these results, it appears that the stress-strain rate relation in the tested specimen is represented by Equation 4 with the absence of Bingham yield stress.

From this investigation it is clear that the stress relaxation technique yields stress-strain rate data down to a strain-rate which is about two orders of magnitude below that possible by normal tensile test. Further, the superplastic behaviour along with the presence or absence of Bingham stress can conveniently be explored by an analysis of the relaxation curve. Thus, the stress relaxation test is complementary to the differential strain-rate test in evaluating superplastic behaviour.

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