The Influence of Soda-Lime Substrate Ion Drift on the Resistance of Discontinuous Thin Gold Films

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Conductance drift with time at high fields has been observed with discontinuous gold films on soda-lime substrates. The effect is attributed to ion drift in the substrate between metal islands which gives rise to (i) a small retarding field along the film which modifies current flow at low applied fields, and (ii) a reduction in the trap density within the tunneling barrier which leads to significant increases in film resistance at high fields.

A discontinuous metal film, deposited *in vacuo*, typically consists of small metal islands (of the order of tens of Angstroms in diameter) separated by gaps of widths in the 10–100 Å range.[1-3] Electrical conduction in such films is a thermally activated process with a nonohmic property. It is generally considered that the activation energy is the result of electrostatic charging of the small metal islands[1-5] as electrons tunnel from one to another through the substrate.[3] The nonohmic property is the result of a reduction in the electrostatic energy with applied field.[1-3,5,6]

When an attempt was made to verify the predicted theoretical variation of film conductance with applied field it was found with gold films on soda-lime substrates that the dc conductance drifted with time, particularly at high fields, and that the I–V characteristics were not reproducible (Fig. 1). The results described were only obtained with films deposited on soda-lime substrates, and no similar effects have been noted with either Corning 7059 or Kapton-H substrates, both of which are ostensibly ion free. It was therefore provisionally concluded that the resistance drift was related to ion drift effects in the substrate. Subsequent electron microscopy revealed that the

films were primarily filamentary in structure and that the activated conduction is therefore due to electron hopping between the islands in the discontinuities between low resistance filaments. The filamentary structure has the effect of magnifying the applied field within the film which appears to be a necessary prerequisite for easy observation of the drift effects.

The assumption that the resistance drift is caused by ion migration within the gaps is confirmed by the observation of a residual voltage along the film after the voltage source is removed. This voltage decays exponentially to zero [Fig. 2(a)] with a time constant of the order of 1000 sec which is typical of ion relaxation or dielectric absorption time constants in soda-lime glass.[7] After application of a high voltage the film resistance becomes assymmetrical as a result of the residual voltage effect. A ±4 V/cm low frequency sine wave gave rise to currents of +0.084 μA and −0.112 μA peak, the assymmetry due to a residual voltage of 0.6 V/cm at the time of measurement decaying exponentially with time as the residual voltage decays.

It might be expected that ion migration within the tunneling barrier would modify the tunneling resistance due to changes in barrier shape which is sensitive to both ionic and neutral absorbates.[8-10] In particular,

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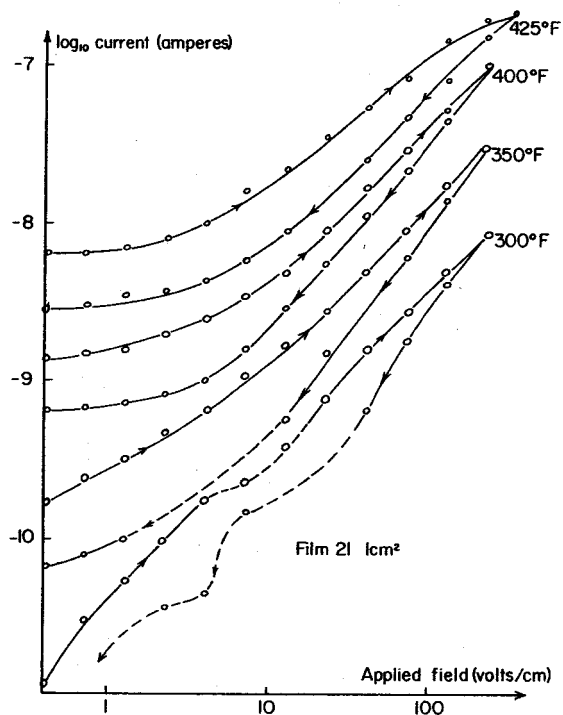
FIGURE 1. Resistance drift with voltage cycling at four temperatures.

positive ions within the barrier are expected to act as weak trapping sites for the tunneling electron.[5,8] Since the electron may then pass through the barrier in a series of short "hops" instead of a single transition, and since the tunneling resistance is an exponential function of the tunneling distance, the removal of distributed trap sites from the interior of the barrier to the interface regions is expected to result in an in-
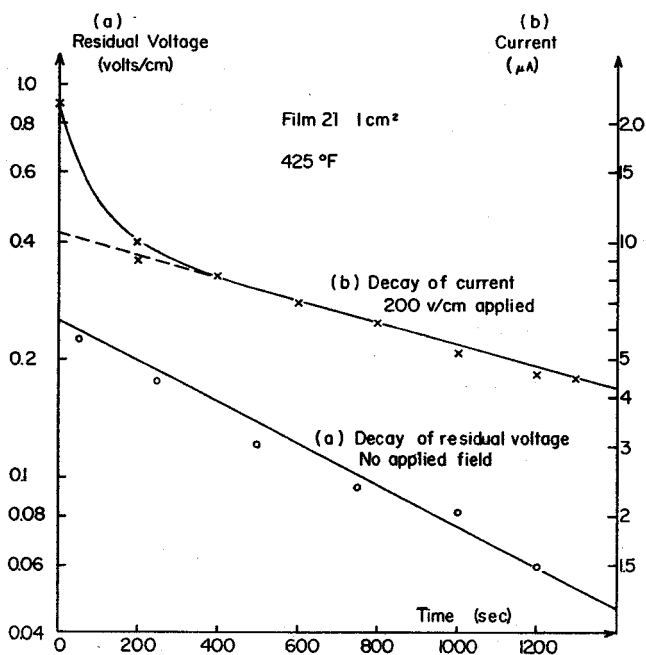

FIGURE 2. Exponential time decay of (a) residual voltage and (b) high field current.
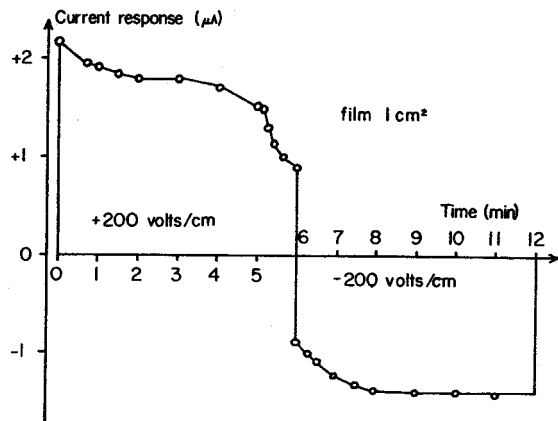

FIGURE 3. Current response to positive and negative voltages.

crease of tunneling resistance. This type of effect would not be apparent when the residual voltage is measured but would cause changes in film resistance of a scale that could not be explained by residual voltages of the order generally measured (<1 V/cm). Figure 2(b) illustrates the variation of film conductance with time upon application of a high field. The reduction is, as expected, not explainable on the simple basis of a small residual voltage. The effect of a reversal of high field is shown in Fig. 3. Initially the current decays [cf. Fig. 2(b)] as the ions drift to the gap interfaces and the resistance appears symmetrical with respect to field polarity at a field level where the residual voltage is negligible. The resistance then decreases as the ions flow back to the interior of the barrier. This last result is also useful as an indication that the high field resistance increase is in fact reversible and is not due to any type of annealing.

The two aspects to the ion drift results must be emphasized, i.e., the concept of the residual voltage, due to ion displacement, and that of tunneling barrier changes due to ion trap redistribution. All results presented here were obtained with one film which displayed the most dramatic drift effects but several others gave similar results, all, however, from the same batch of substrates. Investigation of the effect is continuing.

References

1. C. A. Neugebauer and M. B. Webb, J. Appl. Phys. **33**, 74 (1962).
2. C. A. Neugebauer and R. H. Wilson in *Basic Problems in Thin Film Physics*, edited by R. Niedermayer and H. Mayer, (Vandenhoeck & Ruprecht, Göttingen, 1966).
3. R. M. Hill, Proc. Roy. Soc. (London) **A 309**, 377 (1969).
4. R. Kiernan and D. W. Stops, Nature **224**, 908 (1969).
5. J. E. Morris, 5th Intern. Vac. Cong., Boston, Oct. 1971, J. Vac. Sci. Techol. (to be published).
6. J. E. Morris, J. Appl. Phys. **39**, 6107 (1968).
7. L. Holland, *The Properties of Glass Surfaces* (Chapman and Hall, London, 1964).
8. R. H. Badertscher, Ph.D. thesis, University of Michigan, Ann Arbor, Mich., 1968.
9. F. W. Schmidlin, J. Appl. Phys. **37**, 2823 (1966).
10. A. Modinos, Surface Sci. **20**, 55 (1970).