Nanodot Systems Reliability Issues

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1 The Nanodot Coulomb Block and Discontinuous Metal Thin Films

Metal nanoparticle applications are proliferating in nanoelectronics, (e.g. single electron transistors (SETs) [1], and in electronics packaging [2]. Varied applications require single nanodots, 1-D lines of dots, regular or random 2-D discontinuous metal thin film (DMTF) arrays, or the 3-D "cermet" variant of nanodots embedded in polymer or ceramic. The oblate ellipsoidal nanodot (Fig. 1) is the minimal energy form of a charged dot [3, 4], or a transient shape [5]. Electronic conduction is by tunneling [6, 7], with probability proportional to $exp\ -(2m\Phi)^{½}(4\pi d/h)$, and with an associated electrostatic activation energy at field E_a (assuming $\theta \approx 180°$) [3, 8]:

$$\delta E_1 = q^2/C = (q^2/4\pi\varepsilon R)(2/e)[\sin^{-1}e - \sin^{-1}(e(1-p)/(1+p))]/(1-p) - qRE_a$$

for $E_a < E_{amin} = (q^2/4\pi\varepsilon R)4p(1+p)^{-1}[(1+p)^2 - e^2(1-p)^2]^{-½}$, where p=d/R, R=2r+d, and

$$\delta E_2 = (q^2/4\pi\varepsilon R)(2/e)[\sin^{-1}e - \sin^{-1}(e(1-p)R/((1-p)R+2x))]/(1-p) - qE_a x/p$$

for $E_{amin} < E_a < E_{amax} = (q^2/4\pi\varepsilon R)4p(1-p)^{-2}(1-e^2)^{-½}$,

where $x = ½Re(1-p)\{[([\{2qp/\pi\varepsilon E_a(1-p)^2R^2e^2\}^2+1]^{½}+1)/2]^{½} - e^{-1}\}$

and $\delta E_3 = 0$ at $E_a = E_{amax}$, corresponding to the 0°K coulomb block threshold. In a DMTF of N_0 nanodots, $N_0 exp\text{-}\delta E/kT$ are randomly charged at any time at finite T, and a single SET or coulomb block nanodot is charged $exp\text{-}\delta E/kT$ of the time [1].

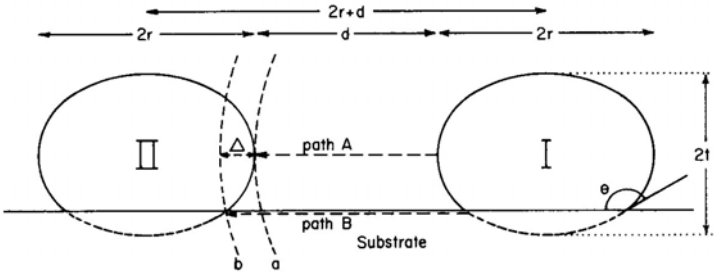

Figure 1 The geometry of 2 ellipsoidal nanodots of eccentricity $e = (1-(t/r)^2)^{½}$ [6, 8]

A great deal of past experimental work on the stability of nanodot characteristics in TMTFs is directly applicable to more recent nanoelectronics applications.

2 Thermal Effects and Thermomechanical Strain

The nanodot system will be supported by a substrate, with electrical connections to the outside world. Conductance shows a strong negative temperature coefficient, and

is also subject to thermomechanical stress due to TCE mismatches. Tunneling gives the system a very high gauge factor, $G=(2m\Phi)^{1/2}(4\pi d/h)$, but the linear variation of G with d at low strain turns over at higher values [6, 9], due to decreasing δE (Fig. 2, [10]) for high eccentricity nanodots with substrate adhesion (i.e. θ<180°.)

3 Air Adsorption

Nanodot adsorption of O_2 by substrate diffusion changes the barrier height Φ [11, 12] (Fig. 3). Other gases have similar effects [13], with H_2 absorption by the nanodot [14].

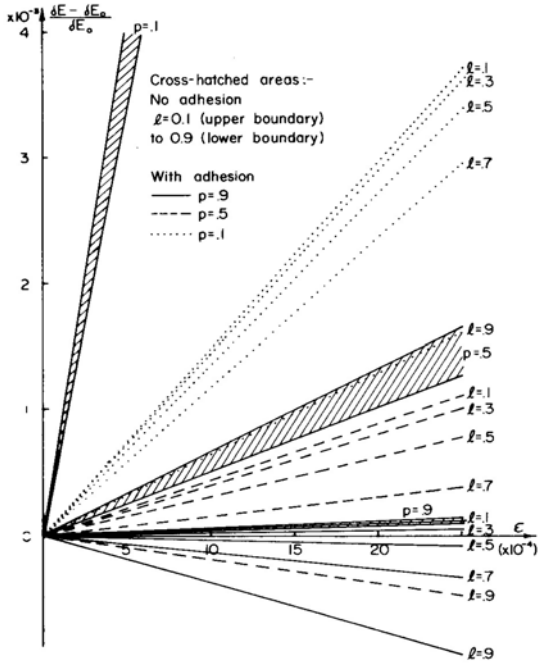

Figure 2 DMTF strain effect on δE [10]

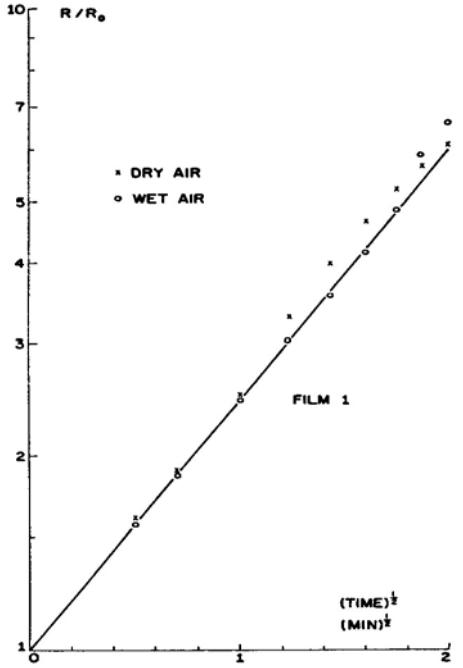

Figure 3 DMTF resistance in air [1]

4 Substrate Ion Drift and Polarization

DMTF currents may decrease with time, due to substrate ion-drift and/or polarization, (Fig. 4) and a residual voltage can be measured across the film after DC application for long periods [15]. Similar effects have been observed in cermets [16].

5 Switching Effects and Noise

DMTFs show both N- and S-type switching [16, 17], with neither understood. Voltage controlled N-type behavior can be explained in negative TCR materials by thermal runaway [18], with a contact space-charge model [7] proposed for S-type [6].

6 Post-deposition Resistance Changes

The weak substrate adhesion needed for DMTF deposition leads to instability as nanodots drift and coalesce. Future commercial applications require fabrication on stable sites. Very oblate nanodots may not be at equilibrium, and may change shape with time as residual adatoms migrate to the nanodot-substrate interface, and as surface self-diffusion from the high curvature edge changes eccentricity (Fig 5 [5].)

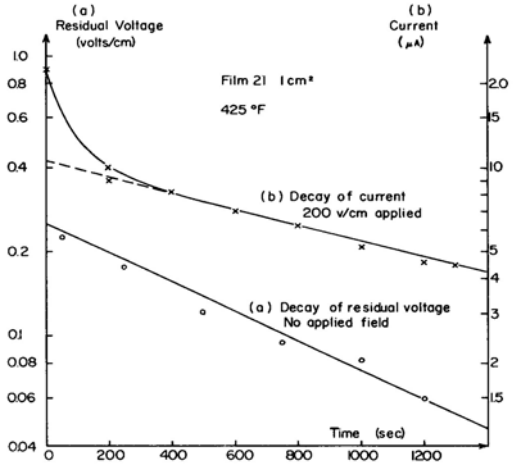

Figure 4(a) "Residual" voltage decay, and (b) high voltage current decay [15]

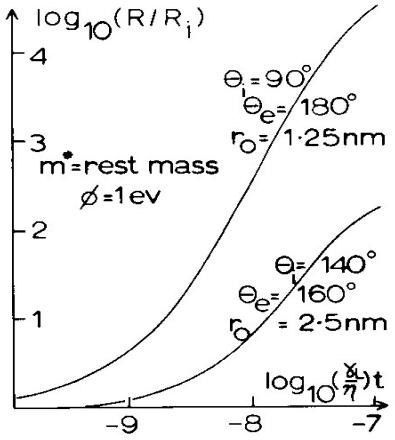

Figure 5 DMTF R(t) model with adatom collection and surface self-diffusion [5]

7 References

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