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# Spheres produced in a graphite film bombarded by electrons

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## Abstract

An approximate relationship is derived between bombarding electron characteristics and the size of carbon spheres produced. using a mechanism proposed by the authors.

**Key Words: spheres (nano/micro), graphite film, electrons**

## 1. Introduction

Experiments of Banhart and Ajayan[1],Ugarte[2,] and Zwanger, Banhart and Seeger[3] present evidence for a thin film of Carbon behaving as a quasi-liquid exhibiting macroscopic properties such as elasticity, surface tension and pressure.

In this paper these ideas, especially the"nanoscopic pressure cell" concept[1], are used and a relationship between bombarding electron characteristics and the size of resultant carbon spheres is derived, drawing an analogy with an air stream striking a liquid surface and forming bubbles.

The electrons channeled into a high current density electric field flux tube, produced due to electric field distortion caused by an inhomogeneity or discontinuity on a graphite target surface is considered analogous to molecules in an air jet blown through a tube onto a liquid surface. The energy / momentum of the electrons is responsible for the pressure in the flux tube producing the Carbon spheres (analogous to liquid bubbles).

## 2. Theory

The pressure $p_e(Nm^{-2})$ exerted by a beam of electrons of current density j $(Am^{-2})$ and energy E(e.v.) incident on a film.

= number of electrons per unit area striking film

x change of momentum per electron per sec

$= j/e \times 2 \times (2mE \times 1.6\times10^{-19})^{1/2}$,

e(C) = electron charge, m(kg )=electron mass,

$1.6\times10^{-19}$ = conversion factor for electron volts to joule,

x 2 factor assumes non energy loss electron reflection.

Substituting $m = 9.1\times10^{-31}$kg $e = 1.6\times10^{-19}$ C

$$p_e = 6\times10^{-6}\, j\, (E)^{1/2} \qquad (1)$$

$p_e$ is the electron pressure at the target, assuming the target surface, accelerating field and electron beam to be homogeneous and uniform.

In practice the surface of the target will not be uniform in all regions, thereby upsetting the uniformity and homogeneity field assumption and changing the electron pressure to

$$p_e = \eta(R)\, 6\times10^{-6}\, j(E)^{1/2} \qquad (2)$$

Factor $\eta(R)$, which is a dimensionles quantity, arises from the non uniformity of the target surface and the consequent distortion of the accelarating field from parallelism, plays a key role in forming the spheres. It provides the necessary mechanism for amplifying the field and electron density needed to get the electron pressure to a sufficiently high value to produce the required buckling of the lattice towards a sphere of radius r. These additional electrons come from the neighbourhood of the region surrounding the inhomogenity.

The mechanical pressure required to produce a spherical shell of radius r(m) in a layer within lattice of graphite film is given by Poisson law in elasticity

$$p_m = 2\sigma\, t/r \qquad (3)$$

$\sigma$=tenstile stress (Pa), t= film thickness (m):

at equilibrium, from equations (2) and (3), (*i.*c., $P_m = P_e$)

$6 + 10^{-6} E^{1/2} j\, \eta(R) = 2\sigma\, t/r$

**hence , $Ej^2 r^2 = K$ ; where $K = (\sigma^2 t^2 / 9\eta^2)\, 10^{12}$**

is the relati on ship between bombarding electron parameters and relationship the size of carbon spheres produced.

**Order of magnitude of $\eta$**

Substituting experimental values of E and j employed and the size of spheres obtained in the HVTEM experiments[3]

E =1.25 Mev, $j=2x10^6$ $Am^{-2}$ in equation (1)

$p_e \sim 10^4$ Pa :

using r=10nm, $t=3.4x10^{-10}m$, $\sigma$=36 GPa in equation (3)

$P_m \sim 10^{10}$ Pa

Hence $\eta$ (R) $\approx 10^6$

The electron density augmentation required therefore, from the neighbourhood of a sphere is for a single electron an additional million.

Since the number of electrons falling on unit area of target per sec.

$=j(Am^{-2})/e(c)$

$\sim 10^{26}$,

$10^6$ is relatively a small fraction of the total available electrons ie., the reduced density region surrounding a sphere position is limited to a small area.

The postulated mechanism is hence reasonable and practically feasilble.

## 3 Discussion

In support of the feasibility of the mechanism of sphere formation proposed, the following evidence is available.

(i) Spheres are not formed all over the film surface but limited to small regions where surface deformities exist to amplify the electron pressure. Macroscopic analogy of a similar type phenomenon would be a direct lightning strike to ground through a lightning conductor.

(ii) Some experimental support of the above model is available in the paper of Zwanger et al[3] where the following observations appear:

"The formation of onions was observed only close to the edge of holes. We never succeeded in producing onions by irradiating carbon films away from a hole".-pp449.

"Graphite was partially disordered by the intense electron beam before the formation of a few small ions on the surface of graphite crystals began" .pp446.

(iii) Experiments performed by the authors[4] with an arc at very low voltage (~ 40V) which is close to a millionth of the energies employed in the electron microscope experiments yielded substantially larger spheres Applying the approximated relationship, $j_1(E_1)^{1/2} r_1 = j_2 (E_2)^{1/2} r_2$ to the arc discharge experiments of Zwanger et. al[3] and ours we would expect at 40 Volts, microspheres 1μm to14 μm which is close to what we have obtained experimentally: (15μm to 240μm ). considering the approximations incorporated in the theory and expression used. (Note : at 1.25 Mev Zwanger obtained sphere diameters from 3 nm, to 80 nm)

(iv) The proposed model would indicate that the conditions favouring larger carbon spheres would be low energies, low current densities and very coarse target surfaces.

(v) The mechanism considered here would also apply to cylinders (eg., nanotubes) with the poisson epuation reducing to $p = \sigma t/r$. A low voltage arc experiment [5] produced tubes ~50 μ diameter.

## 4 References

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