LETTERS TO THE EDITOR

PHYSICS

Langmuir-Blodgett Multi-monolayers as Thin Film Dielectrics

AN investigation has been carried out into the feasibility of using Langmuir-Blodgett multi-monolayers¹ of stearic acid as a thin film dielectric². It has been found that these layers are stable under vacuum and that it is possible to evaporate aluminium over them without damage, as demonstrated by Handy and Scala³ investigating tunnelling infilms 25–100 Å thick.

Layers have been deposited on metallized slides, counter electrodes evaporated over them and some of the electrical properties of the resulting sandwiches measured.

The thickness of the layers appeared very uniform, the standard deviation of capacitance/unit area on each slide being commonly as low as 3 per cent, that is, of the same order as the accuracy to which the areas of the base and counter electrodes can be produced and measured. The variation from slide to slide was higher, about 10 per cent, due to the difficulty of duplicating the exact geometry of the electrodes.

The other electrical measurements were considerably more variable; the tangent loss angle ($\tan \delta$) showed a standard deviation of up to 25 per cent and the breakdown strength (V/cm) varied on one slide by a factor of ten. (Twenty-four capacitors were produced and measured on each slide.) These variations are tentatively attributed to variations in surface pressure or vibration during deposition and it is hoped that as the production parameters become better understood and controlled these variations will be minimized.

Each monolayer deposited is a "two dimensional" crystal⁴ and consequently tends to bridge gaps and discontinuities left by the previous layer. This gives these multilayers the interesting property of tending towards greater smoothness as they get thicker. A stearate multilayer 225 Å thick (stearic acid 25 Å/molecule) has a maximum dielectric strength of 1.3×10^6 V/cm with 3×10^{-10} amp leakage current at 1×10^6 V/cm, while a 3700 Å multilayer can withstand 2.6×10^6 V/cm with a leakage current of 1×10^{-11} amp at 10^6 V/cm. Over the same range of thickness the loss angle ($\tan \delta$) had dropped from 0.02 at 225 Å to 0.006 at 3700 Å, that is, the dielectric strength increases with thickness. The variation in loss angle with frequency followed normal thin film behaviour. There was no significant variation of capacitance with frequency.

Due to the low dielectric constant of stearic acid (2.5) the charge/unit area is low (about 6×10^5 pF/cm²), though there is some evidence to suggest that the dielectric constant can be varied by altering the proportions of metal stearate in the multi-monolayers.

The multi-monolayers are surprisingly thermally stable. They can be heated to 90° C in damp air over prolonged periods (the melting point of stearic acid is 69° C) without damage and have also been repeatedly and rapidly

cycled from liquid nitrogen temperature to 50° C in air without change in their electrical properties.

L. HOLT

Associated Electrical Industries, Ltd.,
Harlow Research Laboratory,
Essex.

Received May 10, 1967.

¹ Blodgett, K. B., and Langmuir, I., *Phys. Rev.*, **51**, 964 (1937).

² Hawkes, P. L., *Thin Film Integrated Circuits*, **5**, 304 (AEI Engineering, 1965).

³ Handy, R. W., and Scala, L. C., *J. Electrochem. Soc.*, **113** (1966).

⁴ Srivastava, V. K., and Ram Verma Ajit, *Solid State Commun.*, **4**, 367 (1966).

Does a Moving Body appear Cooler?

THIS question was raised recently by Landsberg¹. Affirmative answers were given by Fremlin², Noerdlinger³ and Williams⁴ in agreement with currently accepted theory. Landsberg⁵ points out that the transverse Doppler effect and the equipartition theorem used by the authors mentioned equally admit a Lorentz invariant temperature as well as the accepted theory. With this view I agree, but question paragraph (c) of his letter, where he gives a general case against the orthodox transformation. He considers two bodies in uniform relative motion, these bodies being large enough to allow heat transfer at right angles to the direction of motion. Landsberg argues that if the bodies are identical no transfer of heat can take place, while the orthodox transformation requires the moving body to be cooler and so inducing heat (that is, energy) transfer.

Let each of the two identical bodies emit an amount of radiation L_0 as measured by an observer at rest relative to the body. The transverse Doppler effect now requires that the observer on the other body, moving with a speed V , receives amount of radiation

$$L_0 \sqrt{(1 - V^2)/c^2}$$

Hence each observer emits L_0 and receives $L_0 \sqrt{(1 - V^2)/c^2}$. Each observer thus thinks there is a flow of energy away from him, as is required by the orthodox theory for temperature transformation.

This idea of apparent energy transfer is not confined to temperature considerations. Consider the collision between two perfectly elastic balls, each of proper mass m_0 , moving with speeds u , $-u$ along the x -axis of an observer B . By solving the equations of conservation of mass and momentum, the speeds afterwards will be given by $-u$ and u . Consider now an observer A relative to whom observer B has a velocity V along the direction of the moving balls. Using standard velocity addition laws, A measures the speed of the balls before the collision as

$$\frac{V+u}{1+\frac{uV}{c^2}} \quad \text{and} \quad \frac{V-u}{1-\frac{uV}{c^2}}$$

while after the collision he measures them as

$$\frac{V-u}{1-\frac{uV}{c^2}} \quad \text{and} \quad \frac{V+u}{1+\frac{uV}{c^2}}$$

Observer B measures the energy of the first ball, both before and after the collision, as

$$\frac{1}{2} \frac{M_0 u^2}{\sqrt{1 - \frac{u^2}{c^2}}}$$

He does not observe any energy flow during the collision.

Observer A measures the energy of the first ball before the collision as