Foreword

The thin-film papers in this issue are an outgrowth of IBM research and development in laboratories at Poughkeepsie, Kingston, New York, Zurich, and San Jose. Some of the papers are device-oriented, while others represent fundamental research and theory.

The extent of thin-film studies indicated by these papers will surprise no one who has followed recent developments in electronic circuitry and high-speed computers. In spite of the use of transistors and modern miniaturized circuit techniques, the increasing requirements placed on electronic machines have made them larger and more complex, so that their speed and efficiency are often limited by power dissipation or even by the rate of signal propagation, which is nearly the speed of light. Under these circumstances, the potential importance of small, low-power, thin-film elements is at once evident.

The magnetic properties and switching characteristics of evaporated permalloy films were first reported in 1955 in the pioneering work of M. S. Blois and of R. L. Conger. In 1956 superconducting, thin-film elements were developed by both J. W. Crowe and R. L. Garwin. Since then, development efforts in industrial laboratories and universities have mushroomed in the general area of thin films. Along with the increasing development interests there has been a corresponding, although somewhat smaller, increase in the use of thin films for the investigation of fundamental theory.

While the rewards in thin-film work are great, the difficulties are often greater; for beneath the metallic luster and apparent perfection of most thin films lies a jumble of impurities and imperfections so complex that they may well be described as a metallurgist's nightmare. Deposition of films in a "good" vacuum of 10^{-6} to 10^{-7} mm Hg frequently results in the collision with the surface of more gas molecules per second than metal atoms. In spite of the resultant impurity content of such films, they generally contain less impurities than films produced by electroplating or sputtering. Good purity in films can be achieved by very-high-speed deposition techniques or normal deposition of a few angstroms per second in an ultra-high vacuum of 10^{-9} mm Hg, but even then they are likely to exhibit certain peculiarities of structure typical of films. For example, metal films evaporated onto substrates at low temperatures are in a high state of disorder, while at higher temperatures agglomeration occurs, so that the films may not be smooth or not even continuous. Even single-crystal films produced on cleavage surfaces of rock salt or mica possess a number of stacking faults and imperfections uncommon in bulk materials.

In spite of these difficulties, work reported in the literature is increasing exponentially as research workers become more aware of the possible applications of thin-film techniques. In some cases, for example the alkali metals, thin films evaporated in high vacuum are the only form in which high-purity material can be obtained for the study of photoelectric phenomena and conductivity. On the other hand, the existence of highly disordered material in films deposited at low temperatures makes them useful for the study of annealing rates. Furthermore, the development of electron-microscopy techniques in the last ten years, particularly by Menter and his group, has greatly increased the usefulness of films in the study of structural imperfections. The energies associated with imperfections in a film several hundred angstroms thick may not be identical to those in bulk materials; however, the ability to "see" the imperfections and their motions during annealing makes this a powerful tool, which has already been exploited with considerable success by Menter, Pashley, Bassett, Wilsdorf, Wehlan, Silcox, Hirsch and others.

While many investigators have been occupied with structural problems in films, others have apparently successfully controlled or ignored them and achieved considerable success in using films for the study of fundamental phenomena. Of particular note has been the observation of decreasing conductivity of films with decreasing thickness due to surface scattering of conduction electrons, as originally described theoretically by Fuchs (1938) and Sondheimer (1952). Related effects have been observed and explained to a lesser extent for the more complex galvanomagnetic, thermoelectric, and photoelectric effects. Because of simple geometrical considerations, thin films have also had wide application in studies of optical absorption, penetration of high energy particles, metallic corrosion, catalysis, and gas adsorption.

Experiments with thin superconducting films have played an important role in testing a number of the predictions of recent theoretical developments in superconductivity, notably the theory of Bardeen, Cooper, and Schrieffer (1957). Measurements of the infrared and microwave absorption and transmission in thin superconducting films by R. E. Glover and M. Tinkham (1956) have provided direct evidence of the energy gap separating the superconducting and the normal state and have been used to determine the magnitude of the energy gap in a variety of materials. More recently, such measurements by Ginsberg, Richards, and Tinkham (1959) have indicated the possible existence of fine structure in the energy gap. The attenuation of magnetic fields passing through thin superconducting films has been used by A. L. Schawlow (1958) to determine the magnitude of the superconducting penetration depth, while the temperature dependence has been studied more recently by Sarachik, Garwin, and Erlbach (1959-60). Considerable progress has also been made in understanding the dependence of penetration depth on film thickness and purity content by Schawlow (1958) and Ittner (1960).

In the field of magnetism, an outstanding achievement of the method of thin films has been the observation of spin wave resonance in permalloy films by Seavey and Tannenwald in 1958. The spins are pictured as being pinned at the film surfaces, but free to resonate between the surfaces much like a violin string with, however, only the odd modes being excited by the ac field. Perhaps even more excitement has been generated in the last year by the magnetization studies of Neugebauer using nickel films evaporated and measured in the same high vacuum of 10^{-9} mm Hg. His measurements indicate that magnetization is independent of film thickness even for films as thin as 27 A. These results are in contradiction with the spin wave calculations of Klein and Smith (1951) and Glass and Klein (1958) and the earlier experimental work of Crittenden and Hoffman and of Jenson and Nielson (1953) in which a decrease in magnetization with decreasing thickness was predicted and observed. It is currently thought that the discrepancy in experimental results is due to subtle structural differences or to the greater purity of the films which were measured and produced using modern high-vacuum techniques.

Although there may not be full agreement as to the interpretation of these conflicting results, they do demonstrate the importance of controlling the purity and structural properties of films being used for any investigation. In considering films for device applications, such problems as control and reproducibility become even more pronounced.

It is not surprising, therefore, that many of the papers in this Journal are concerned with problems of film fabrication and structural effects; these papers cover subjects such as ultra-high deposition rates for producing pure films, agglomeration in superconducting films, epitaxially grown films, and the determination of crystallite size by x-ray diffraction. Other papers in the Journal deal with such diverse subjects as the attenuation of magnetic fields by superconducting films, magnetic domain wall structures, the effect of film edges on device characteristics, and a theoretical calculation of anisotropic surface scattering of conduction electrons.

While no attempt has been made at completeness, a broad spectrum of thin-film research and development is represented in this Journal. In bringing these papers together in one publication, the authors and editors hope that the work will contribute to the advancement of the science and technology of thin films.

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