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Direct observation of magnetic domain structure in plated-wire memory devices

Manufacture of computer memory store elements from plated-wire devices is now an established procedure. Typically 2500 Å of permalloy is electrodeposited on a thin (0.005 in.) copper-beryllium wire which carries a current to ensure a circumferential easy axis in the coating. Subsequent annealing reduces the magnetostriction to close to zero protecting the device from the effects of accidental stress [1]. In order to determine the coercive force and other magnetic properties of the permalloy it is necessary to control carefully the nature of the surface onto which electroplating occurs, the conditions of electrodeposition and the annealing treatment. The absence of a routine method of studying domain and ripple structures of electrodeposited films has complicated the search for optimum conditions of production. As surface observations are severely hampered by the necessary roughness of the permalloy coat [2] we decided to work in transmission with an electron microscope. In view of the thickness of the permalloy it was necessary to use a high voltage microscope [3] and our observations were made at 1 MeV.

We first established the specimen position and degree of objective lens excitation for the Hitachi microscope at the Berkeley Nuclear Laboratories so that the domain structure was preserved in the permalloy (coercive force 10 Oe). Specimens were prepared by cutting at 45° to the wire axis with the fine range of a spark cutting machine. The copper beryllium core was removed to a distance of 0.3 mm from the cut, by complexing with ammonia, this distance being chosen to facilitate electron microscope examination with the minimum possible disturbance of the memory element. The resulting "pen quill" specimen is shown in a scanning micrograph (Fig. 1). Note the rough circumferential line of contrast demarking the limit of removal of the copper beryllium (the contrast is the reverse of what we had expected).

Once prepared, specimens were glued to the edge of a 3 mm diameter ring with the "pen quill"

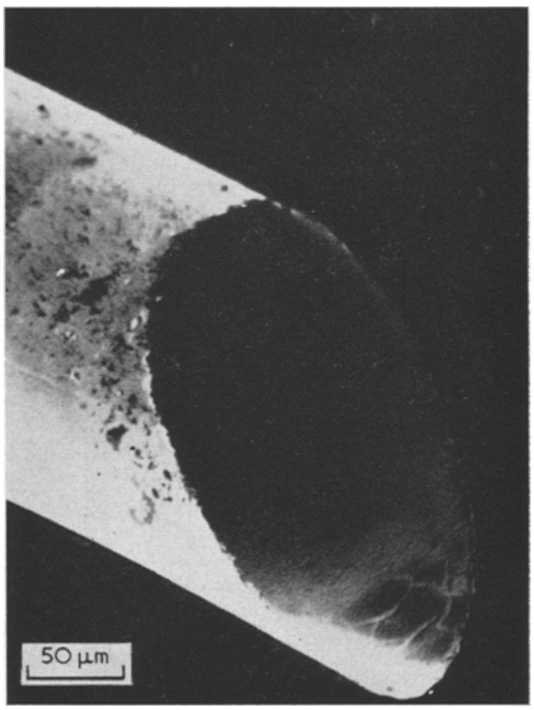

Figure 1 Pen quill specimen ready for transmission electron microscopy. The darker region visible at the top left hand corner of the wire shows the presence of underlying copper beryllium.

at its centre and mounted in the electron microscope as shown in Fig. 2. In focus and out-of-focus pictures were then taken wherever possible for a whole range of plated wire specimens. We were unable to see magnetic contrast when the electron beam passed through both the upper and lower portions of the "quill", but contrast was easily visible through the single thickness up to a position where the curvature gave an electron path of 3 500 Å. Extreme cases of results are shown in Figs. 3 and 4. Magnetic detail was found to be more visible when the objective lens was focused on a plane above the specimen and the typical out-of-focus distance was approximately 1 cm.

In Fig. 3a the region of observation is shifted slightly to the right of that indicated in Fig. 2. The shadow at the left hand side is caused by the upper surface of the pen quill. Transmission

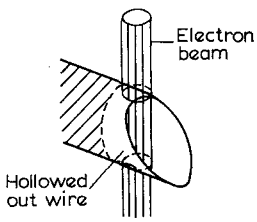

Figure 2 Diagram showing how the specimens were mounted in the transmission electron microscope.

through the lower surface reveals approximately circumferential domain walls (black/left, white/right – the parallel scratches E E′ are in the direction of the wire axis). Fig. 3b reveals the roughness of the permalloy coat (the shadow in the lower left corner is caused by the upper surface of the pen quill).

Fig. 4 was a characteristic result for a rough permalloy coating requiring a relatively high current to change the sense of magnetization. The domain walls wander about and there is strong ripple contrast. On the other hand relatively smooth specimens with low reversal currents are typified by Fig. 3. It seems quite likely that the domain walls in this specimen are the asymmetric Neel walls predicted by Hubert [4] and reported previously by De Blois (see reference [4], while the walls in Fig. 4 are Bloch walls. However, further experiments are required to investigate this point. According to the analysis of Hoffmann [5] which is apparently successful for permalloy specimens [6] the mean wavelength of the ripple of a specimen similar to that shown in Fig. 3 implies a stray field of approximately 2 Oe.

It was also possible to study the relationship between the domain walls and features acquired from the substrate surface, such as die marks from the wire drawing process (e.g. Fig. 3 at E and E′) and etch pits which had been deliberately introduced. Some specimen heating un-

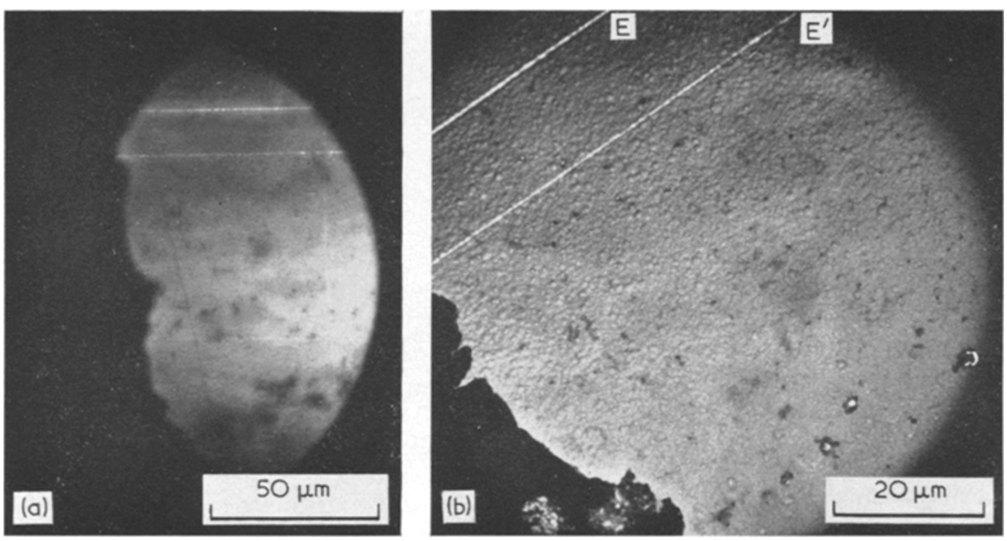

Figure 3 Transmission electron micrographs of the specimen shown in Fig. 1. (a) over-focused; (b) in focus and at a higher magnification.

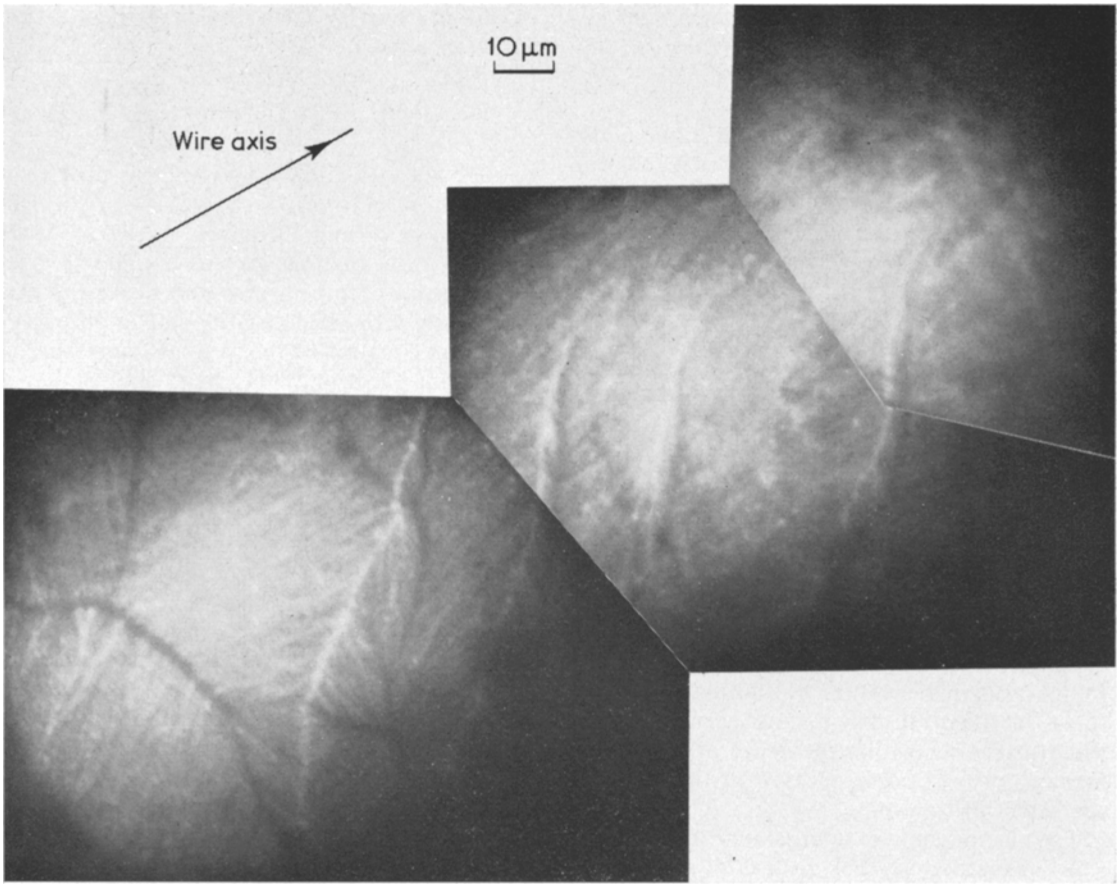

Figure 4 Over-focused micrograph of one surface of a pen quill with a rough permalloy coat (out-of-focus distance approximately 1 cm).

doubtedly occurred as it was possible to induce recrystallization by the use of large condenser apertures (this was also achieved when studying a specimen in a 100 keV microscope). Baltz [7] found a recrystallization temperature of approximately 400°C for permalloy with a grain size of 1200Å.

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