# LAMINATED FERRITE MEMORY FABRICATION

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# I. INTRODUCTION

This report describes in detail the technology developed for fabricating laminated ferrite memory arrays. The composition described herein, referred to as Ferrite B, has the following characteristics:

$H_c$ = coercive field = 0.4 Oe
$S_w$ = switching coefficient = 0.3 Oe-μsec
$B_r$ = remanent flux density = 1200 gauss
$S$ = squareness = 0.9
$T_c$ = Curie temperature = $110^{\circ}C$

Another composition, referred to as Ferrite A, is available from the RCA Ferrite Memory Operation, Needham Heights, Massachusetts, and is currently being used for the production of high-drive, high-speed laminated ferrite memory arrays with 64 x 64 crossovers per plane, as well as ferrite cores for high-speed linear select memory systems.

## II. LAMINATED FERRITE MEMORY FABRICATION

There are six steps in the fabrication of a laminated ferrite memory plane: (1) Ferrite powder preparation, (2) ferrite slurry preparation, (3) ferrite sheet manufacture, (4) conductive line fabrication, (5) laminating, and (6) firing.

### A. FERRITE POWDER PREPARATION

The composition used for this work is $Zn_{.45}Mg_{.55}Fe_{1.55}Mn_{.45}O_4$ and is identified as Ferrite B material. The formula indicates 0.45 at.% of Zn, 0.55 at.% of Mg, etc. A typical batch contains 244.0 grams of zinc oxide, 309.2 grams of magnesium carbonate (heavy grade), 823.0 grams of iron oxide ($Fe_2O_3$), and 344.4 grams of manganese carbonates. These materials plus 1900 $cm^3$ of methyl alcohol are placed in a steel mill of 6-inch I.D., 10.5 inches deep, and charged with 7 kg of 3/4-inch steel balls. This charge is milled for two to three hours at 100 rpm. After milling, the mixture is dried at 150°C, passed through a 4-mesh screen, and placed in fireclay crucibles for calcining. The material is heated to 1900°F in 4 hours, held for 2-1/2 hours and cooled with the kiln. The calcining atmosphere is air in a globar kiln. The calcined powder is placed in the same mill used for mixing, 2000 $cm^3$ of methyl alcohol are added, and the mixture is milled for 20 hours. After drying as before, the material is ready for use in preparing the blading slurry.

### B. FERRITE SLURRY PREPARATION

A mixture of 640 grams of calcined ferrite, 44 grams of Butvar 76, 20 grams of Flexol D.O.P., 4 grams of tergitol non-ionic TMN, and 480 $cm^3$ of methyl ethyl ketone are placed in a mill identical to the mill used for mixing and grinding, and is milled for 20 hours. After milling, the slurry is put into a glass jar and rolled at 12 rpm until ready for use. This mixture is then used for doctor blading on silicone rubber. Slurries to be used on glass contain 580 $cm^3$ of methyl ethyl ketone instead of 480 $cm^3$. Slurries are passed through a 200-mesh screen as they are loaded in front of the doctor blade. This is necessary to remove undissolved or unmixed clumps.

## C. FERRITE SHEET MANUFACTURE

Sheet is made by drawing the doctor blade through a pool of slurry loaded in front of it. The doctor blade is a smooth straight edge which can be set at any desired height above a suitable substrate surface. The height of the blade regulates the thickness of the ferrite slurry applied to the substrate. During drying, the adherence of the slurry to the substrate must be sufficient to prevent lateral shrinkage; all shrinkage should be vertical. Glass and silicone rubber have been found to be the most suitable substrates on which to blade the film. Highly polished chromium surfaces also are satisfactory, but release of the film is more difficult. Thorough wetting of the dried film with water greatly facilitates release. The vertical drying shrinkage ranges from 5:2 to 7:1. Thus, to obtain a 3-mil-thick sheet, a doctor blade setting of 15 to 20 mils must be used. This ratio depends upon the viscosity of the slurry and the speed of draw of the blade. No definite figures are available for these variables. The viscosity of the slurry has not been controlled nor has the speed of draw. The specific gravity of the bladed unfired sheet is about 2.8. During drying of the sheet, care must be taken to prevent draughts across the sheet. Draughts cause uneven drying and can cause the film to crack or craze. Drying should be slow enough to allow drying to occur from the bottom to the top. If the top dries first, lateral shrinkage takes place on the surface causing orange peeling and crazing. Sheets thicker than 10 mils are not feasible due to the difficulty in drying the film slowly and uniformly enough. Thicker sheets can be made by laminating as many thin sheets as desired; blocks up to 1 inch thick have been made in this way.

## D. CONDUCTIVE LINE FABRICATION

There are three methods of putting conductive lines in the ferrite: (1) To embed a solid wire. (2) To squeegee a conductive paste through a mask onto a flat surface and then doctor blade over the conductor pattern. (3) To form grooves in ferrite and then fill with a conductive paste or powder. The material used for conductors must withstand ferrite firing temperatures and atmospheres. In most cases, this requires that platinum, palladium, rhodium, iridium, or osmium be used. Gold is suitable for ferrites maturing below the melting point of gold.

Wires of platinum, palladium, or gold have been used. Shrinkage of the ferrite during firing (about 17 percent) causes sufficient stress on the ferrite in the vicinity of the solid metal to crack the ferrite, unless the ferrite wall is about ten times as thick as the diameter of the wire. If the ferrite is heavy enough not to crack, the compressive forces on the wire are sufficient to fracture the wire along slip planes in the metal. This has been shown by radiographs of such samples. In the case of gold conductors, the gold melts, then contracts into isolated segments along the line causing an open circuit. Gold-plated platinum, rhodium, and palladium wires have been used successfully. The gold melts, allowing the shrinking ferrite to slide along the wires. However, the mechanical problems involved in stretching many wires parallel seemed to make this method impractical.

Pastes have been made of all of the suitable metallic powders. Patterns are photoetched in beryllium copper or stainless steel masks. The paste is squeegeed through the masks onto a glass or silicone rubber substrate. Ferrite slurry is bladed over the patterns laid down through the masks. The dried ferrite film is then peeled off including the conductive patterns. This process is limited by the mechanics of the mask. Long, fine, closely spaced conductors are not feasible with the present state of the art.

Grooves in the ferrite are produced by machining the desired pattern in a lacquer phonograph record master (Fig. 1a). RTV60 silicone rubber is then cast over the master producing a male rubber master (Fig. 1b). Ferrite slurry is bladed over the master (Fig. 1c). The dried film is peeled off (Fig. 1d). The grooves are then filled with conductive powder.

Grooves are being produced by embossing a plain green ferrite sheet. The embossing punch (Fig. 2b) is made by electroplating nickel on a lacquer master (Fig. 1a). The nickel master is given a light chromium flash to facilitate removal of the embossed film. Referring to Fig. 2, embossing is accomplished by loading the die (g) as follows: bottom punch (a), nickel master (b), plain ferrite sheet (c), aluminum foil (d), rubber pad (e), and top punch (f). The loaded die is heated to 90$^{\circ}$C and a pressure of 3000 psi is maintained for about 30 seconds. The die is immediately unloaded and the embossed sheet removed from the master at 60$^{\circ}$C. The grooves are then filled with conductive powder.

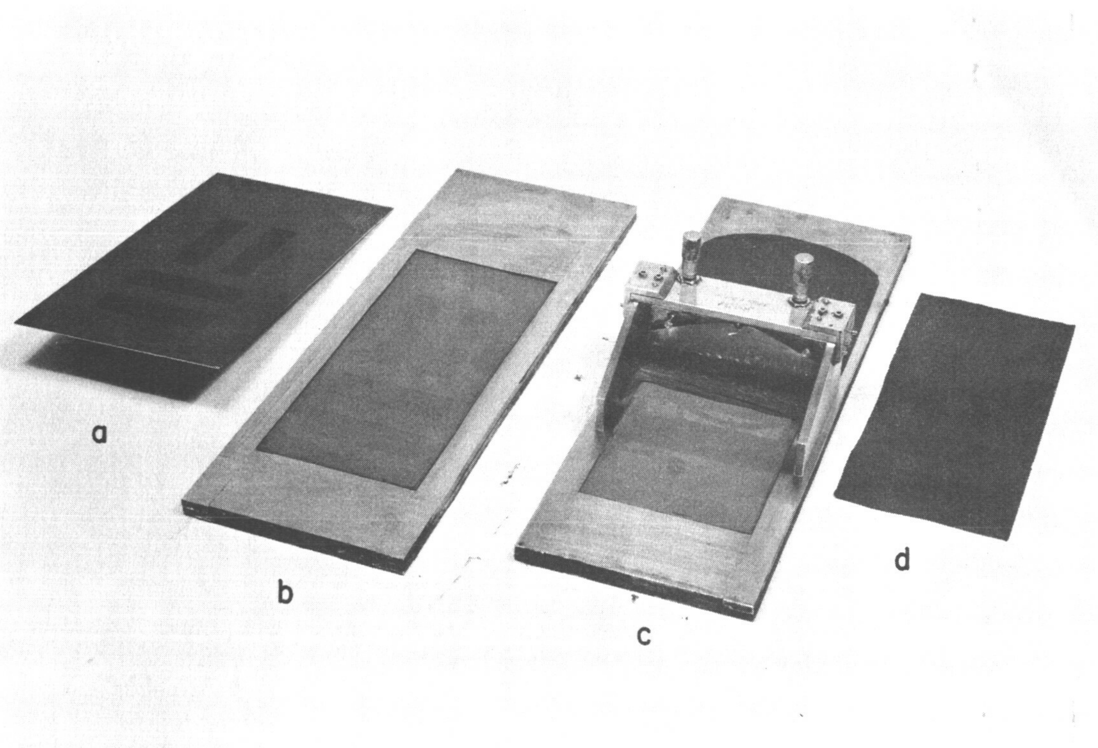


Fig. 1. Doctor blading ferrite slurry over rubber masters to make grooved sheets.

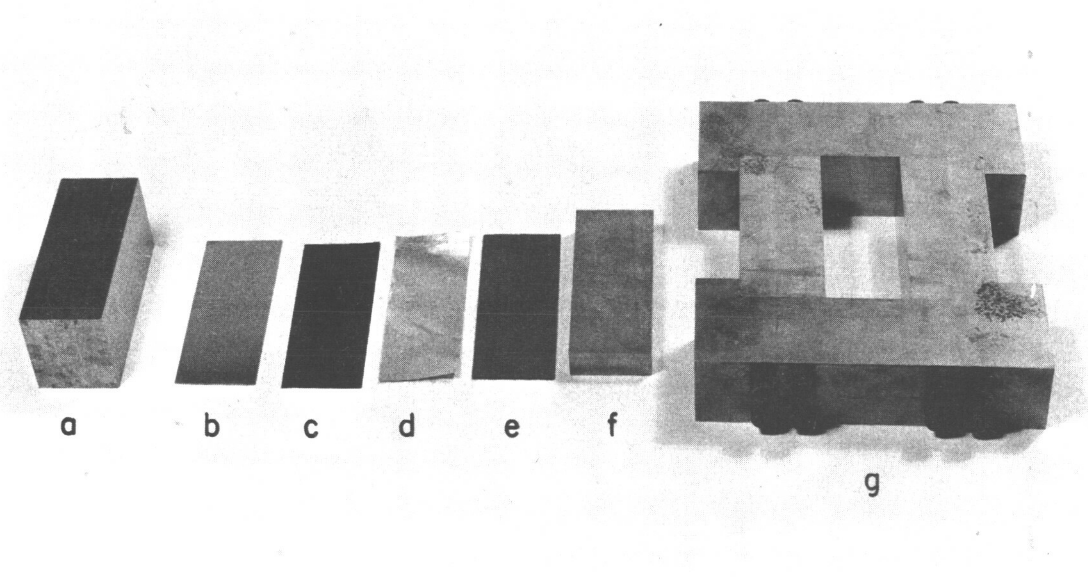


Fig. 2. Die and load to produce grooved ferrite sheet by embossing.

## E. LAMINATING

All laminating is done in essentially the same way. The die (j) in Fig. 3 is filled in the following order: bottom punch (a), rubber pressure pad (b), aluminum foil (c), filled word-line sheet (d), blank spacer sheet (e), filled digit-line (f), aluminum foil (g), rubber pressure pad (h), and top punch (i). A pressure of 2000 psi is applied to the punches and the temperature is increased to 90$^{o}$C. The stack is removed hot. The die and all components are cooled before refilling.

Figure 4 shows the dies and punches used for the laminates currently being made: (a), the 256 x 64; (b), the 256 x 100; and (c), the 512 x 200.

## F. FIRING

Firing is done on flat ground aluminum oxide setters. One green ferrite plane is placed between a pair of spaced setter plates. The spacing is about 2 mils greater than the thickness of the ferrite. This limits warping. The firing schedule is to go to 2300$^{o}$F at 450$^{o}$F per hour, hold 2 hours and then cool with the kiln. The atmosphere is air. Annealing is required in nitrogen. The schedule for this is to go to 2050$^{o}$F at the rate of 450$^{o}$F per hour, hold 2 hours, and then cool with the kiln.

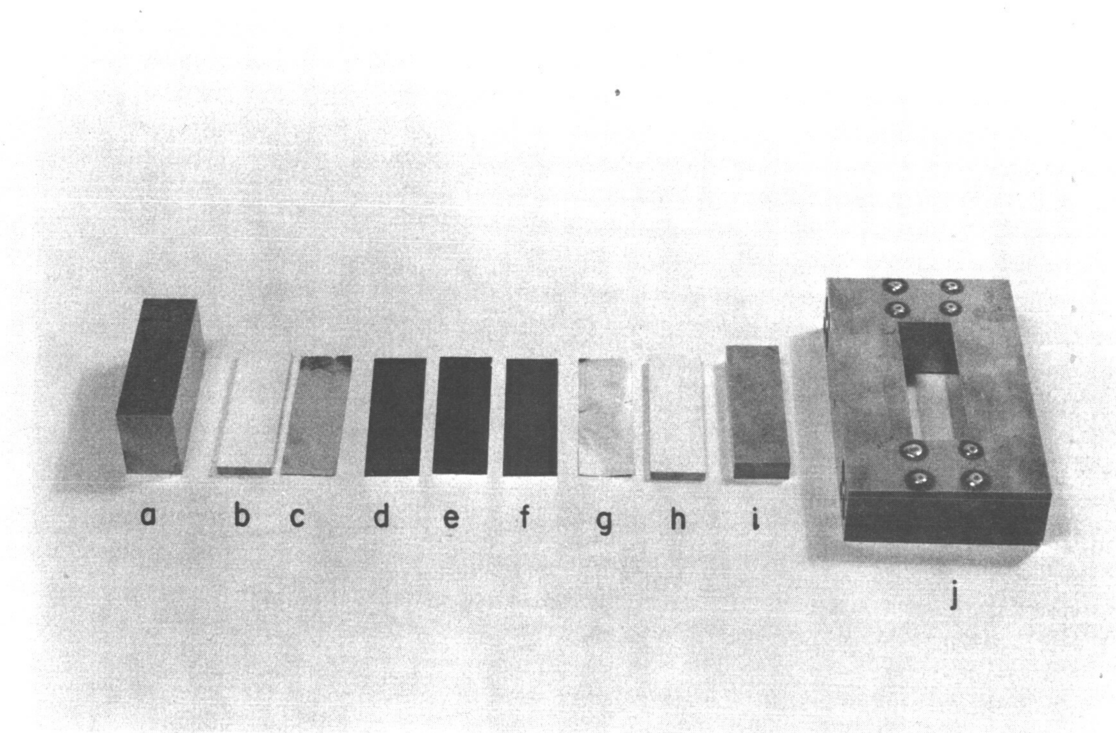


Fig. 3. Die and load for laminating green ferrite sheets.

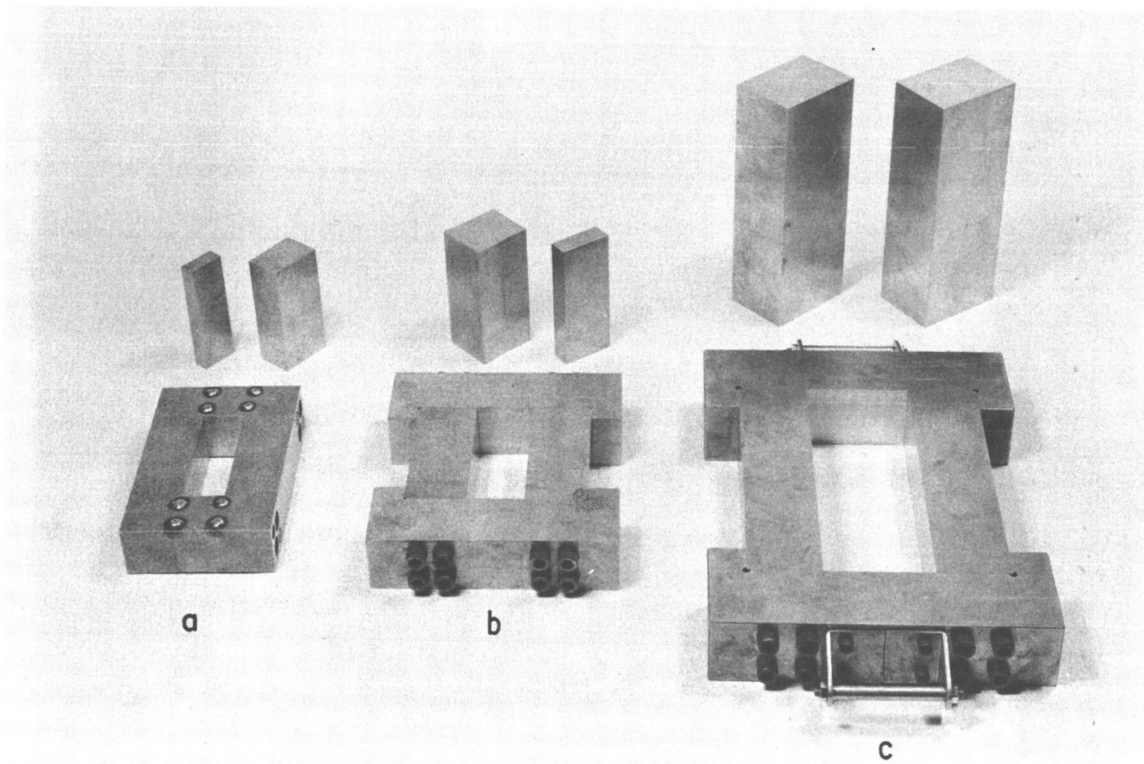


Fig. 4. Laminating dies.