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FABRICATION AND PERFORMANCE OF A LAMINATED
NONVOLATILE NONDESTRUCTIVE READOUT MEMORY CORE

Final Report

By H. F. Jordan, Jr.
Department 845

Published March 1978

Prepared for the United States Department of Energy
Under Contract Number EY-76-C-04-0613.

**Kansas City
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Final Report
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A technique has been developed for the fabrication of 5.08 mm diameter cores using 0.025 or 0.013 mm thick magnetic sheet material. The technique uses the photoresist used in the photochemical etching process to serve as the adhesive as well. A test technique for the nondestructive readout characteristics of the cores has also been developed.

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SUMMARY

Small toroidal magnetic cores are used in a new nonvolatile nondestructive readout memory where performance depends on core properties that typically are not used and not measured. Commercial cores used in initial development work performed unpredictably and were in limited supply because the manufacturer had discontinued production. Trial use of a variety of similar commercial tape wound cores failed to yield a satisfactory substitute. Performance variations are felt to be related to the tape construction of the purchased cores and to the magnetic material processing.

During this endeavor, laminated cores were constructed in an effort to obtain predictable and improved core performance. A process was developed for the fabrication of 5.08 mm diameter cores using 0.013 mm thick magnetic sheet stock. Photolithography and chemical etching were used to produce arrays for lamination. The photoresist remaining on the lamination was determined to be useful as the lamination adhesive. Array handling using magnetic holding devices proved feasible.

A technique for the evaluation of core performance was devised that relates to the unusual transverse field used in the application of the cores. With this new technique, it was determined that the output of both the tape wound core and the laminated core is improved at increased flux densities, which can be accomplished by increasing turns or dimensional changes. The laminated core provides superior performance at higher flux density while the tape wound core is superior at lower flux density. The assembly is being designed to operate at the higher flux density range; therefore, laminated cores will provide the best performance.

DISCUSSION

SCOPE AND PURPOSE

This project was undertaken to find a means of producing a laminated magnetic core with an outside diameter of approximately 5.08 mm. A laminated construction technique using magnetic material with a thickness of 0.025 or 0.013 mm was proposed to achieve an unusual configuration (Figure 1) with potential for improved performance. Purchased cores of conventional construction have proven unsatisfactory in the past.

Before undertaking this development effort, eight different types of purchased cores of various tape construction were tried. They exhibited unpredictable and unsatisfactory or marginal performance.

The cores are used in a product in which an unusual pulsed transverse field is applied by means of the read winding (Figure 2). This transverse field temporarily realigns the magnetic field within the core and under the sense winding, causing an output whose polarity is dependent on the original direction of core magnetization. This readout technique depends on core properties that are not significant in conventional applications.

In Figure 2, read field strength at the sense winding will cause eddy currents as indicated by the spiral. These eddy currents generate an opposing flux and are reduced by laminating the core as shown in Figure 1.

Read field strength is a function of core geometry and the input ampere-turns. Cores constructed of lamination (Figure 1) can be fabricated to dimensions that provide the best field strength. Core shapes such as the square illustrated in Figure 3 are feasible using the same processes used for round laminated cores. In square cores, it is easy to wind the read field directly over the sense winding, thus maximizing read field strength at the part of the core under the sense winding.

Furthermore, construction details of the tape cores include a weld in the tape which will distort the core characteristics, and variations in tape wrap spacing which will also affect the magnetic performance in this application. It is likely that these factors contribute significantly to the recorded variations in performance. Those factors are avoided in laminated construction.

LAMINATED CORE

TAPE WRAP

Figure 1. Magnetic Material Configurations for Laminated and Tape Wrap (Conventional) Cores

Figure 2. Pulsed Transverse Field Applied by Means of Read Winding

Figure 3. Square Core Shape Feasible With New Process

ACTIVITY

The activity on this project was directed at finding a fabrication process with a potential for producing laminated cores and a test technique that relates to core performance.

Fabrication Process

Cores were laminated using three processes. Each process used chemical etching to provide laminations of washer shapes from sheet stock. Cores were then produced from stacks of adhesive-coated washer laminations.

Two difficulties were immediately obvious:

- Handling of the small, thin, and feather-like parts through a wet etch and stacking process; and
- Application of a thin coat of adhesive to such small, light parts.

Three processes were tried; one of the three was considered to have greater potential for production.

AZ111 Photoresist-Adhesive Process

This process uses the photoresist remaining on the part after etching as the adhesive for laminating the core layers. There are three advantages to this technique:

- Man-hours are saved as a result of the dual usage of photoresist;
- A thin 0.0025 mm coating is applied with a dipping process that requires no additional evaluation or investment; and
- The adhesive coating covers the precise area of the lamination.

In addition, the magnetic property of the sheet metal permitted the use of magnetic fixturing to handle arrays of laminations. As a result, a group of three rows and nine columns of laminations could be maintained in a fixed position relative to each other during and after the etch and during the transfer to the stacking fixture. The strength of the magnet used to transfer the array from the etch fixture to the stack fixture was not sufficient to attract all of the array, but much stronger magnets are available which will make the process more workable. A vacuum probe was found to be an acceptable alternate handling technique even though it took more time.

Tooling holes were punched in each of two corners of rectangular 89 by 190 mm sheets of magnetic material. Both 0.025 and 0.013 mm thick sheets of HyMU 800 were used. A coating of Shipley's AZ111 photoresist was applied to the sheets by dipping and withdrawing at a rate of 66 mm per minute. The sheets were dried for 50 minutes at 66°C. Phototooling was used with a light source and Shipley's AZ303 chemical developer to fix the resist over the areas to protect it from the etchant (Figure 4). A water rinse was used to wash off the developer.

Panels with this resist pattern were etched on the holding fixture shown in Figure 5.

The holding fixture was constructed of titanium which does not react with the etchant. A magnetic holding feature was provided to maintain the location of the metal laminations on the tool surface. The excess metal was etched away using a solution of nine parts Hunt's Rapid Circuit Etch and one part muriatic acid. A water rinse followed and the top plate containing the laminations was separated from the magnetic base. At this point, the magnetic attraction had been removed and the laminations remained in position because they were wet.

The laminations were transferred from the top plate to the stacking fixture shown in Figure 6.

The magnetic feature of the stacking feature was designed to attract the laminations away from the top plate. However, some of the laminations remained with the top plate, proving that a stronger magnet is required. A vacuum probe proved to be an alternate method of handling the laminations without damaging them.

Stacks of 20 laminations were baked for 20 minutes at 138°C. A plate with an array of holes corresponding to the fixture pins was placed on top of the laminations to maintain lamination-to-lamination contact. Completed cores exhibited adhesion of lamination with significant squeeze-out apparent around the edges.

Cores were also stacked on core holders as shown in Figure 7.

Item 2 in Figure 7 was a friction fit on Item 1. Baking at 82°C for 30 minutes provided reasonable lamination adhesion and avoided squeeze-out. It is apparent that temperature-pressure tradeoffs will result in any amount of squeeze-out desired. Adhesive thickness and core thickness could be controlled by fixturing.

An analysis of AZ111 shows it to contain phenol formaldehyde resin, a stable thermosetting resin.

Figure 4. Magnetic Sheet With Photoresist Array

Figure 5. Etch Holding Fixture

Sprayed Adhesive Process

Another technique examined during this endeavor was the use of an adhesive to coat the metal in areas where etching was to be prevented.

With this technique, edge definition proved to be poor and notches 0.38 mm deep developed. The adhesive did bond after use in the etchant. American Cyanamid's BR125 adhesive was sprayed on in a 0.0025 mm thick layer using a ratio of one part by weight BR125 to ten parts by weight trichloroethylene. The product was baked at 149°C for 1 hour.

Figure 6. Stacking Fixture

INDIVIDUAL CORE STACK HOLDERS

Figure 7. Individual Core Stack Holders

One of the advantages of using the sprayed adhesive process is that equipment for precision thickness application is already available. The extra operation involved in the application of sprayed adhesive and the poor edge definition were undesirable features.

An alternative approach not tried that would eliminate the notches and poor edge definition is to spray an array after it has been etched.

Dry Film Resist Process

A dry film resist was tried as an array holding mechanism in the transfer of the photoetched laminations to the stacking fixture.

The film tore despite careful handling and it was difficult to dissolve the film in a stack of layers. Further work with thicker resist will be required to determine if this could be a usable process.

Electrical Performance Evaluation

Laminated cores were compared to the initial purchased core in a test fixture designed to simulate the applied read field. A solenoid winding of 100 turns over a 25.4 mm length was constructed as shown in Figure 8 to provide a transverse field approximating that of the use environment.

A rod with provisions for a loop through the center of the core was fabricated to control the position of the core to be tested in the solenoid. A buffer amplifier was fabricated to minimize capacitive loading on the output and also to minimize unwanted signal pickup.

The core tester was used to compare core sensitivity between the best of the sample of ten tape wound purchased cores and a laminated core constructed of 0.013 mm thick material. The 0.013 mm thick material was used in this comparison since tests proved that it has an output approximately 50 percent greater than that achieved with the 0.025 mm thick material. Several laminated cores were tested and it was determined that all cores of similar construction provided similar performance. The tested cores are shown and described in Figure 9.

Application of a 0.3 μ s ramp input current that was varied in amplitude was used to compare core sensitivity to input current variation. A linear sensitivity was indicated with an output that increased linearly as input amplitude increased ($d\phi/dt = v$).

The data plotted in Figure 10 shows the purchased tape wound core operating almost linearly in the region of input current at which the memory application was originally designed to operate. The laminated core exhibited a nonlinear sensitivity with voltage output approaching zero almost asymptotically as input pulse amplitude decreases. The laminated core provides superior

Figure 8. Transverse Field NDRO Test Set

performance at flux densities corresponding to input current amplitudes above 0.4 A (Figure 10) while the tape wound core is superior below 0.4 A. The output of both the tape wound core and the laminated core is improved at increased flux densities, which can be accomplished by increasing turns or dimensional changes. Since the flux density corresponding to the input current operating point in the assembly usage is being increased from 0.1 A to above 0.4 A, the laminated core will provide superior performance in assembly usage.

ACCOMPLISHMENTS

A process was developed to fabricate cores constructed from laminations with adhesive interfacing. Photoresist remaining after etching was found to be usable as an adhesive. The basic material has been found to be a phenol formaldehyde resin dissolved in cellosolve acetate and xylene. Apparently, the initial drying of the sheet material and subsequent photoetch processing leaves the phenol formaldehyde in a B-stage. Subsequent baking at higher temperatures sets up the material.

Figure 9. Tested Core Descriptions

A test technique was developed that permits comparison of core performance in response to the application of a transverse flux pulse. This is significant because assembly performance has been unpredictable using standard core tests. This new technique opens up the possibility of screening out the best of the purchased cores for possible use in the assembly and it is a technique for evaluating the potential of any core for this memory assembly application. With this technique, it was determined that the output of both the tape wound core and the laminated core is improved at increased flux densities, which can be accomplished by increasing turns or dimensional changes. The laminated core provides superior performance at higher flux density while the

Figure 10. Core Sense Output Voltage for Input Amplitude Variations

tape wound core is superior at lower flux density. Since the assembly is being designed to operate at the higher flux density range, laminated cores will provide the best performance.

FUTURE WORK

A significant amount of development work remains to be done before laminated cores can be put into assemblies intended for Design Laboratory evaluation. Areas requiring additional work include the following:

- Perfect the array handling process as a matter of economics;
- Determine the appropriate time-temperature relationship for the photoresist bonding operation (outgassing and complete molecular crosslinking are significant concerns);
- Evaluate various magnetic materials commonly used in cores including material thickness and its affect on performance

(materials thicknesses less than those used now are available);
and

- Improve core dimensions and winding parameters to maximize sense voltage output.

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ELECTRICAL: Magnetic Cores

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