

PRODUCTION OF THIN FILM NETWORKS WHICH  
UTILIZE CHROME-GOLD CONDUCTORS

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# PRODUCTION OF THIN FILM NETWORKS WHICH UTILIZE CHROME-GOLD CONDUCTORS

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## ABSTRACT

Thin film networks (TFNs), designed by Sandia Laboratories, Albuquerque, are manufactured by the Bendix Corporation, Kansas City Division, for DOE programs. The majority of the TFNs fabricated at this division utilize gold films 3 to 9  $\mu\text{m}$  thick evaporated over a chromium film. The chromium film is evaporated over sputtered tantalum nitride film, and the substrate material is 0.027 in. (0.686 mm) thick alumina.

The TFNs must have high film adhesion characteristics, meet high bondability requirements, and allow stable electrical parameters. Various production techniques ensure these high reliability TFNs.

## OVERVIEW

The manufacturing processes yield highly reliable TFNs to support the fabrication of approximately 1000 hybrid microcircuits (HMCs) a month. Figure 1 illustrates all the processes through which TFNs manufactured by Bendix are routed before delivery to the HMC manufacturing facility.

## TFN DESIGN CRITERIA

Figure 2 illustrates the designs used on several TFNs manufactured by Bendix. The basic guidelines for design of these TFNs are as follows:

- o Conductor widths are 0.005 in. minimum.
- o Conductor spacings are 0.005 in. minimum or 0.010 in. if soldered components are located on the conductors.

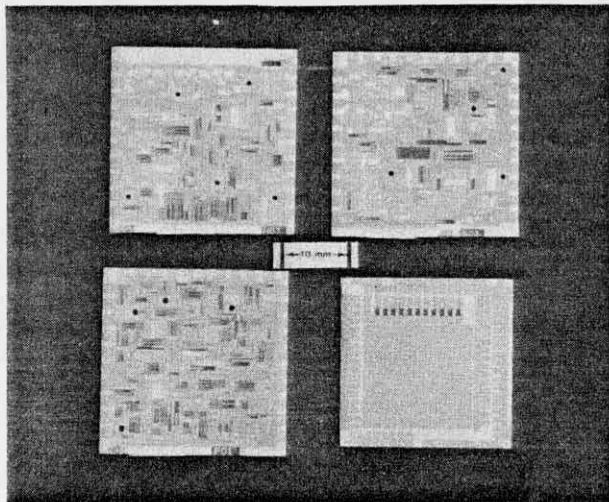


Figure 2. Typical Logic Type TFNs

\*Operated for the U.S. Department of Energy by The Bendix Corporation, Kansas City Division, under Contract No. DE-AC04-76-DP00613. This article was supported by the Division of Military Application.

- o Resistor probe pads are 0.020 in. by 0.020 in. minimum.
- o Capacitor solder pads are 0.010 in. metallization extension around periphery of the maximum capacitor size.
- o Standardized resistor sheet resistivity is 100  $\Omega/\text{sq}$ .
- o Resistor trim depth limit is a visual guide on resistor by means of a small step.

## SUBSTRATE PROCESSING

Substrate material procured is 3.75 by 4.50 by 0.027 in. 99.5 percent alumina. The minimum lot size purchased is 150 substrates. Each lot is submitted to the following test.

Feature Tested	Sample Size	Limits
Thickness	22	$\pm 0.002$ in.
Finish	22	10 $\mu\text{m}$ maximum
Camber	22	0.004 in./in. maximum
Density	5	3.8 $\text{g}/\text{cm}^3$
Surface Defects	22	18 pits and burrs maximum
Grain Size	3	1.3 to 2.5 $\mu\text{m}$
Laser Reflectivity	22	Comparison to a standard only
Bondability	5	Minimum pull strength 0.75 lbs. (0.015 by 0.007 in. lead frame TC bonded to metallized substrate)

## Via Drilling of Substrates

In TFNs requiring conducting paths between frontside and backside metallization, the prime fabrication method is laser drilling of the vias. Figure 3 illustrates a typical 4.50 by 3.75 in. substrate which has been laser drilled. The via diameter is 0.030 (+0.006, -0.003) in. with a positional tolerance of 0.007 in. as related to the backside surface of the substrate and to the two datum holes centered on each side of the substrate. This substrate also has laser-drilled component mounting holes. The round holes are

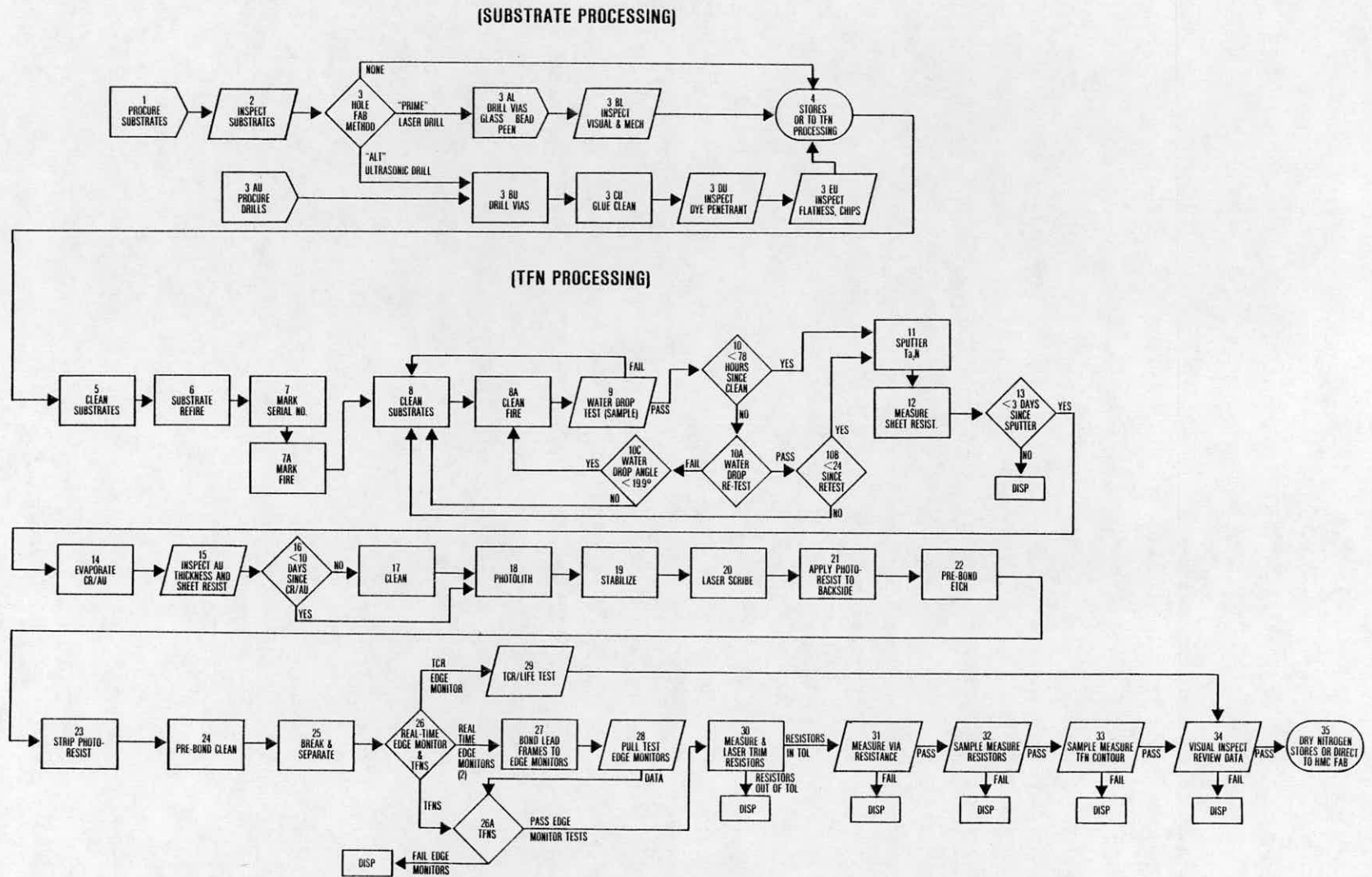


Figure 1. Thin Film Networks Flow Chart

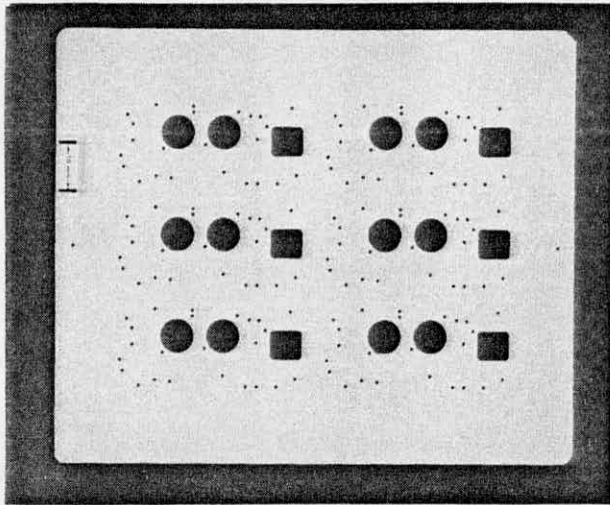


Figure 3. Laser-Drilled Substrates

controlled to a diameter of  $0.293 \pm 0.004$  in. and the "square" holes to a dimension of  $0.256 \pm 0.003$  in. by  $0.282 \pm 0.003$  in. Before via drilling, a protective coating of polyvinyl alcohol is applied to the substrate. The coating protects the substrate during drilling and subsequent glass bead peening operations. Glass bead peening of laser-drilled vias is an important step to providing adhesion in the vias. During laser drilling, the alumina ceramic is liquified, and a portion of this liquified ceramic solidifies as "debris" around and in the via. Surface debris may be removed by scraping; however, glass bead peening is necessary to remove debris from the via walls. One thousand mesh spherical glass beads sprayed through a 1/2-in. diameter nozzle pressurized to 70 psi have been found satisfactory in removing this debris.

An alternate process that uses an ultrasonically-driven diamond drill is also used for model building and for occasional schedule support. This process is currently only used as a back-up process since it makes drilling and inspecting the vias more costly and the yield at drilling is lower. The via hole size can only be controlled to  $0.035 \pm 0.008$  in. (almost twice the tolerance that can be controlled with laser drilling). Also, a dye penetrant test is required to determine if micro-cracks are present around each via.

#### TFN PROCESSING

##### Cleaning, Refiring, And Marking TFNs

When the substrates are received in the TFN fabrication department, they are cleaned with deionized water ultrasonically agitated to remove the protective film and any gross foreign materials. The substrates are then refired to reconstitute the alumina surface in the via areas where the original as-fired surface has been disturbed. The refire time is four hours at 1400 to 1450°C

depending on which vendor's substrate is being processed. If no via drilling was performed on a substrate, refiring is not required.

After refire, the substrates are marked on the backside with a serial number for in-process identification and the two-part epoxy ink used for the marking is fired at 860°C for one hour.

Next, the important cleaning steps before sputtering are performed. The room air in the cleaning facility is controlled. The particle count meets Class 10,000 requirements (Fed. Std. 209B, Para. 5.1.2.); and relative humidity is controlled at 60 percent maximum.

The process steps for cleaning substrates are as follows.

1. Trichloroethylene clean in ultrasonic cleaner for two minutes at room temperature.
2. Acetone clean in ultrasonic cleaner for two minutes at room temperature.
3. Detergent clean in ultrasonic cleaner for two minutes at room temperature.
4. Deionized water clean in ultrasonic cleaner for two minutes at room temperature.
5. Deionized cold water rinse in ultrasonic cleaner for two minutes.
6. Deionized hot water (175°F) rinse in cascade washer for four minutes.
7. Dry in hot laminar flow dry nitrogen dryer for five minutes.
8. Air fire at 860°C for one hour minimum.
9. Store in covered containers.

##### Sputtering and Chrome/Gold Evaporation

Before sputtering, a sample substrate from each cleaning lot is measured for cleanliness using a deionized water drop test. The contact angle of the water drop is measured within 20 seconds after water contact and shall not exceed 10 degrees. Substrate cleanliness is considered such an important aspect of the processing that time limits between cleaning and sputtering are critical. The flow chart in Figure 1 illustrates options that are exercised if time limits are exceeded.

Air in the sputtering and evaporation facility room is controlled to the same limits as air in the cleaning facility. The tantalum purchased for target material in sputtering thin films is 99.99 percent pure, vacuum-refined, and fully annealed, and the nitrogen introduced during sputtering is premixed with argon (97 percent argon to 3 percent nitrogen). The substrates are sputtered with tantalum nitride to a sheet resistivity range between 70 and 80  $\Omega$ /sq. at a rate of 0.4 nm/s. The sputtered substrates then are routed to the chrome-gold evaporation system in the same containers that were used to store cleaned substrates for in-process storage. The

sputtered substrates are to be completed through chrome-gold evaporation within three days of sputtering. With regard to purchase requirements, the gold bulk must be 99.97 percent pure in slug or wire configuration and the chromium bulk must be 99.97 percent pure in pellet configuration.

The chromium film is deposited at a typical rate of 0.1 nm/s to a thickness of 30 nm. The chromium layer is used as an "adhesive" layer between the alumina substrate and the subsequent gold film. The gold film is deposited at a typical rate of 6 nm/s to a thickness varying between 2.7  $\mu\text{m}$  to 9.0  $\mu\text{m}$  depending on the HMC application needs. The gold is deposited in the same equipment as the chromium, and on TFNs with vias, the substrates are rotated to maximize the gold deposition within the vias. If backside metallization is required, the substrates are turned over in the holding fixture and the above chromium and gold evaporation steps are repeated. After deposition is complete, the gold is measured for thickness and sheet resistivity. Typical sheet resistivity limits are 15 m $\Omega$ /sq. maximum for the 3  $\mu\text{m}$  thick gold and 6 m $\Omega$ /sq. maximum for the 6  $\mu\text{m}$  thick gold.

#### Photoprocessing and Stabilization of TFNs

The facility requirements for photolith processing are the same as the cleaning facility requirements. If the photolith process is not started within 10 days of chrome and gold evaporation, and if dry film resist is to be used for conductor processing, the metallized substrates require cleaning before photoprocessing. Dry film resist is required to protect interior walls of vias during etching. On TFNs without vias, a wet film resist is used, and the cleaning process is not required. The cleaning process is as follows:

- o Vapor degrease over boiling trichloroethylene for 5 minutes.
- o Rinse with acetone.
- o Rinse with isopropyl alcohol.
- o Rinse with running deionized water.
- o Blow dry with dry nitrogen.

During the various stages of photoprocessing, the metallized substrates must be maintained in a dry environment, which is obtained by using desiccant in the storage containers. During the photolithography and etching steps, the substrates should not be exposed to temperatures above 200°C, and if dry film resist is present on the substrates, they should not be exposed to temperatures in excess of 50°C.

To list the complete photoprocessing steps would require a paper in itself, so they will not be covered in detail here. Experience has shown that all photoprocessing steps should be completed as quickly as possible with the following typical time limits:

- o Rinsing after etching - 15 s maximum;
- o Chromium etch time - 20  $\pm$  2 s;

- o Wet film resist removal - one hour maximum after etching;
- o Dry film resist development - 12 hours maximum after exposure;
- o Dry film gold etching - within 3 days of development;
- o Chromium etch after gold etch - 30 s maximum; and
- o Photoresist stripping - 5 min. maximum after last etching operation.

After all photoprocessing steps are completed, the substrates with the etched conductor and resistor patterns are routed to the stabilization furnace for thermal stabilization of the tantalum nitride resistors, which brings the sheet resistivity of the tantalum nitride film up to approximately 100  $\Omega$ /sq. The stabilization parameters are temperature (300  $\pm$  15°C) and time (120  $\pm$  5 min.).

#### Separation of TFNs

The substrates are then in the condition shown in Figure 4. The individual TFNs on the substrate and the real time edge monitors, whose purpose will be discussed later, are "scribed" along their individual outlines for separation later in the processing. The scribing operation is performed using a YAG laser with beam placement controlled manually or by a tape drive unit. The kerf made by the laser should be a continuous scribed line with a maximum width of 0.0015 in.

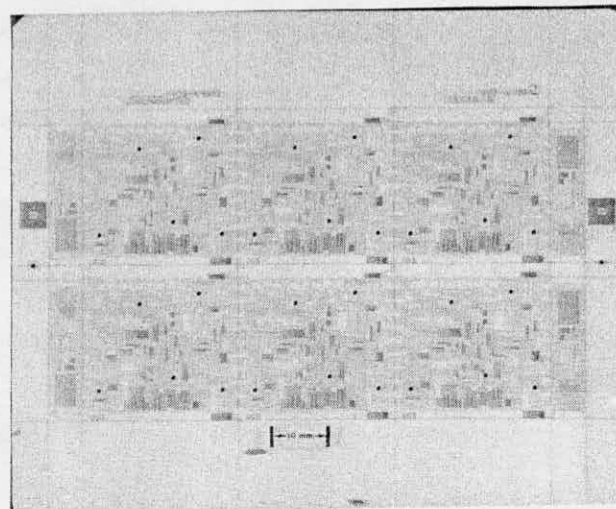


Figure 4. Multiple Image Photoprocessed TFNs With Real Time Edge Monitors

A pre-bond etch process removes any chromium which may have "migrated" to the gold surface because of elevated processing temperatures. Chromium on the gold conductor surface will interfere with thermocompression (TC) bonding steps during HMC manufacture. If evaporated gold is present on the backside of the TFN for

ground plane purposes, a protective photoresist coating must be applied to this backside surface before etching and stripped off after etching. This pre-bond etch material is a solution of ceric ammonium nitrate, nitric acid, and deionized water. The etch time for the substrates is  $60 \pm 5$  s. Within 15 s of etching, the substrates are rinsed in deionized water for 6 min.

The substrates are then pre-bond cleaned using the following procedure:

- o Wash in boiling trichloroethylene 10 minutes.
- o Rinse in room temperature isopropyl alcohol for one minute.
- o Wash in boiling detergent 10 minutes.
- o Rinse in boiling deionized water for one minute.
- o Rinse in cold deionized water for one minute.
- o Rinse in hot (175°F) deionized water for 4 min. in a cascade washer, continue rinse until the electrical resistivity of the water exiting the chamber is 10-M $\Omega$ -cm minimum.
- o Drain and dry substrates in a dry nitrogen chamber.

At this time, the TFNs and real time edge monitors, which are fully prepared for TC bonding, are separated manually by breaking along the scribe lines.

#### Real Time Edge Monitor Processing

Each 3.75 by 4.50 in. substrate has four real time edge monitors which are used for resistor stability testing and metallization adhesion testing. These monitors also can be used for via resistance measurements and photolith alignment and linewidth control measurements. Figure 5 shows a close-up view of the features of a real time edge monitor. (It is identified as a "real time" edge monitor because it "sees" each process at the same time as the TFN undergoes the process.) One edge monitor from each sputter lot is selected for temperature coefficient of resistance (TCR) and resistor life tests. The TCR of the test resistors must be in the range of -60 to -150 ppm/°C when measured at 25, -50, 100 and 150°C. To test the stability of the test resistor, the edge monitor is exposed to a temperature of  $150 \pm 15^\circ\text{C}$  for  $200 \pm 24$  hours. The change in resistance after this temperature exposure should not exceed +0.2 percent.

Metallization adhesion testing is such an important aspect of the processing that one edge monitor is selected from each large 3.75 by 4.50 in. substrate (two are selected on TFN designs with backside metallization) to represent the TFNs that were on that substrate. The quantity of TFNs represented ranges from 6 to 12 with the quantity controlled by the individual sizes of the TFNs and sputtering equipment limitations. On the selected edge monitors, a set of 19 copper alloy (No. 194) lead frames (0.015 in. wide by 0.007 in. thick) are TC bonded to the lead frame bond pads on the edge monitor or to the gold surface to test backside

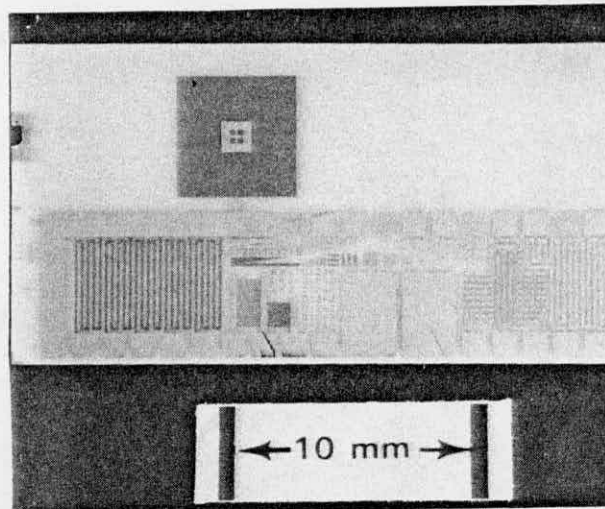


Figure 5. Close-Up of Real Time Edge Monitor

metallization. Ten of each lead are then bent 90 degrees to the bond pad and peel tested. The following test criteria apply to determine the acceptance of the metallization:

#### Frontside Metallization

Minimum Pull Strength	0.75 lbs.
Minimum $\bar{X}$	1.50 lbs.
Failure Mode	No metallization failures in excess of 10 percent of the area of an individual bond site

#### Backside Metallization

Minimum Pull Strength	0.50 lbs.
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#### Laser Trimming of Resistors

All resistors on each TFN are measured, and if required, trimmed to required resistance values using a YAG laser. The spot size of the laser used is approximately 0.001 in., and for proper trimming, a slight flowing of the substrate material should be evident and the resistive film completely removed from the kerf when inspected at 20 to 30X magnification.

#### Inspection of TFNs

In addition to the inspection operations already discussed, the following sample inspection operations also are performed.

- o Resistance measurements are taken on four vias on each large substrate with limits 10 m $\Omega$  for 6  $\mu\text{m}$  thick gold and 25 m $\Omega$  for 3  $\mu\text{m}$  thick gold.
- o One TFN from each group trimmed is placed on the probe tester and each resistor is individually measured.

- o One TFN from each group separated is placed on a shadow graph inspection machine and the profile is visually inspected.

The final operation in the TFN processing is the visual inspection of the TFN. Each TFN is 100 percent inspected for conformance to product drawings and visual inspection criteria specified in joint Bendix/Sandia technology specifications.

#### TFN STORAGE

If they are not immediately needed to support HMC assembly schedules, the TFNs along with their remaining associated real time edge monitors are dried at 100°C for one hour then placed in containers with dessicate for a minimum of 12 hours. Then the TFNs are placed in dry nitrogen storage cabinets in which the relative humidity is maintained below 5 percent after chamber stabilization. If the TFNs are stored less than six months, they

may be used immediately upon removal from storage. If they are stored longer than six months, the TFNs and associated real time edge monitors are pre-bond cleaned again and another edge monitor is processed to represent these TFNs for re-qualification of the TFN metallization adhesion.

#### CONCLUSIONS

The processes discussed are detailed and highly controlled and do provide for DOE HMC applications chrome-gold metallized TFNs which have high film adhesion characteristics, good bondability, and stable electrical parameters.

#### ACKNOWLEDGMENTS

The writer acknowledges the work performed by Bendix and Sandia TFN and HMC technology and processing sections for developing the processes which have allowed product application of chrome-gold metallized TFNs on DOE HMCs.