EFFECTS OF HYDROGEN ON TANTALUM NITRIDE RESISTORS

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OUTLINE

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- SUPPORTING DATA
- SOURCES OF HYDROGEN
- PALLADIUM-HYDROGEN CATALYTIC REACTION
- POSSIBLE SOLUTIONS
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INTRODUCTION

- Part Type: Multichannel Microwave Integrated Circuit (MIC) Hybrid Microelectronic Filter Module for Space Flight Application
  - Analog Hybrid: Thin-Film Alumina Substrate, Dual Transistor, Op-Amp, Digital-Frequency Converter, Diode Chips, Chip Capacitors, Chip Resistors
- Drift Reported in Static Frequency Output from Analog Circuit During +125C Burn-in of Hermetically Sealed Hybrid Section
- Outputs Returned to Normal When Covers Were Removed or Punctured from Hybrid Modules and +125C Burn-in

FILTER MODULE PHOTO

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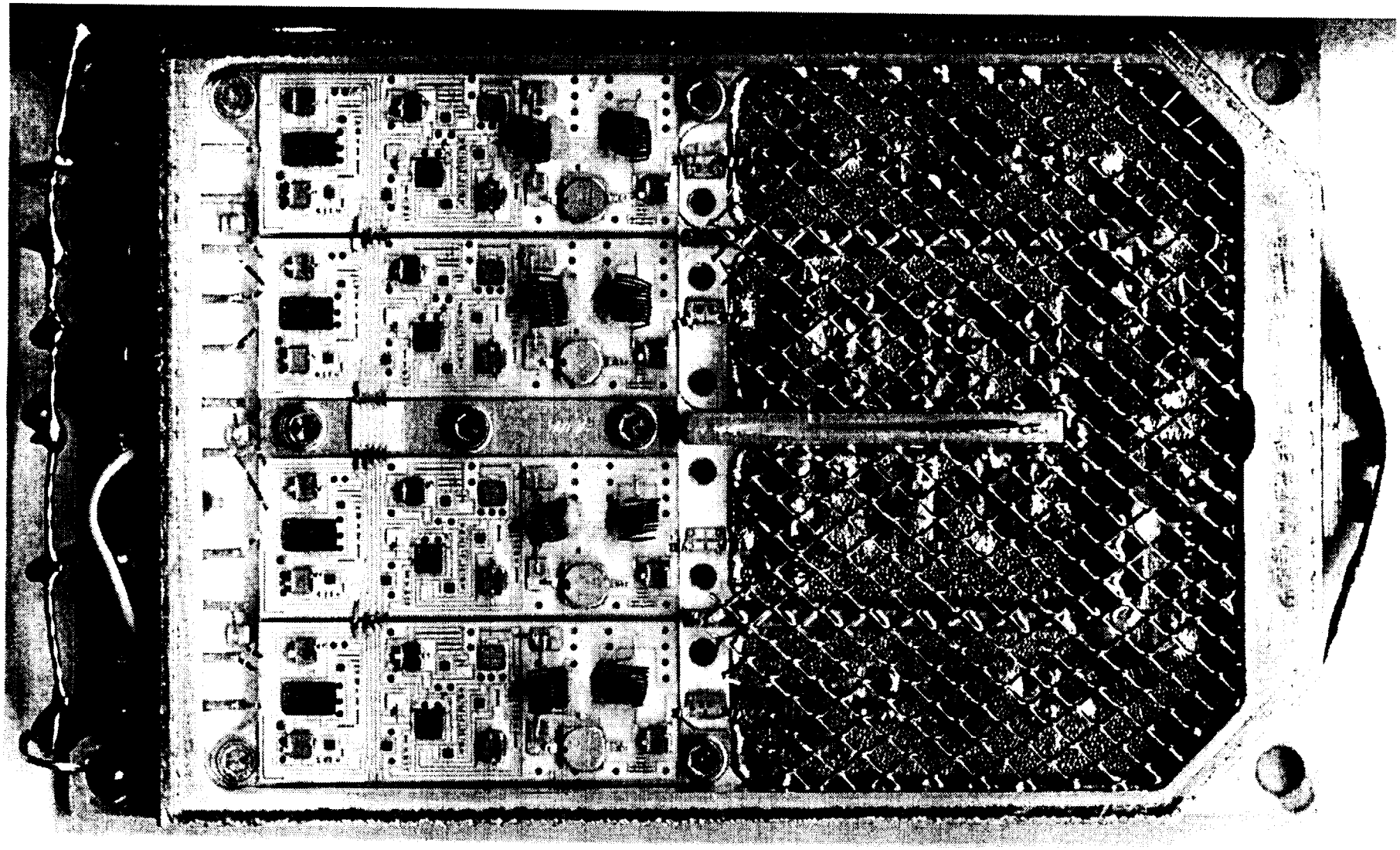

INITIAL FINDINGS

- Design Review of Filter Module by Parts Engineer of RF lumped element filters, detector and analog/digital hybrid section isolated the drift to the hybrid section of circuit.
- Empirical Circuit Analysis, modify sections of analog circuit in a hermetic test evaluation circuit and determine sensitivity to output frequency drift.
- RGA Testing
  - Failed Internal Water Vapor Content Requirement: Module 1 = 6.8%, Module 2 = 8% (>5% Max)
  - Hydrogen: 1930ppm, 4036ppm respectively
  - 80% Nitrogen, 20% Helium
- 150 Hour High Temperature Humidity Test (Electrical Performance Improved Significantly)

INITIAL FINDINGS

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- 72 Hour Vacuum Bake Followed By Sealing RGA Holes (Electrical Performance Normal for all Channels)
- 160 Hour Burn-in @ +85C, DC Bias (1 of 7 channels drifted slightly)
- 96 Hour Bake @ +93C (all channels drifted)
- RGA Testing
  - Met Internal Water Vapor Content Requirement: 1.7%
  - Hydrogen: 1776ppm

INDENTIFICATION OF PROBLEM

- Empirical Circuit Analysis Identified two 35k ohm Tantalum Nitride Resistors that set the bias voltage for each side of a LM194 or a MAT02 matched dual NPN transistor to be very sensitive.
- Computer circuit simulation confirmed this finding. A 20 ohm differential shift in the set resistance values between the 2 chips would result in the observed frequency output drifts.
- EDAX Analysis of the 35k ohm thin film Tantalum Nitride chip resistors identified Palladium in the film.
- A catalytic reaction of Palladium and Hydrogen produces mono atomic hydrogen.
- Filled the filter module cavities with a 4% Hydrogen, 96% Nitrogen gas mixture @ 25°C and monitored the electrical performance for 24 hours. Some channels drifted in a similar pattern witnessed earlier.
- An internal visual and EDAX analysis was performed at the conclusion of this testing. Confirmed Palladium on chip resistors.

X-RAY EDS OF TANTALUM NITRIDE RESISTOR

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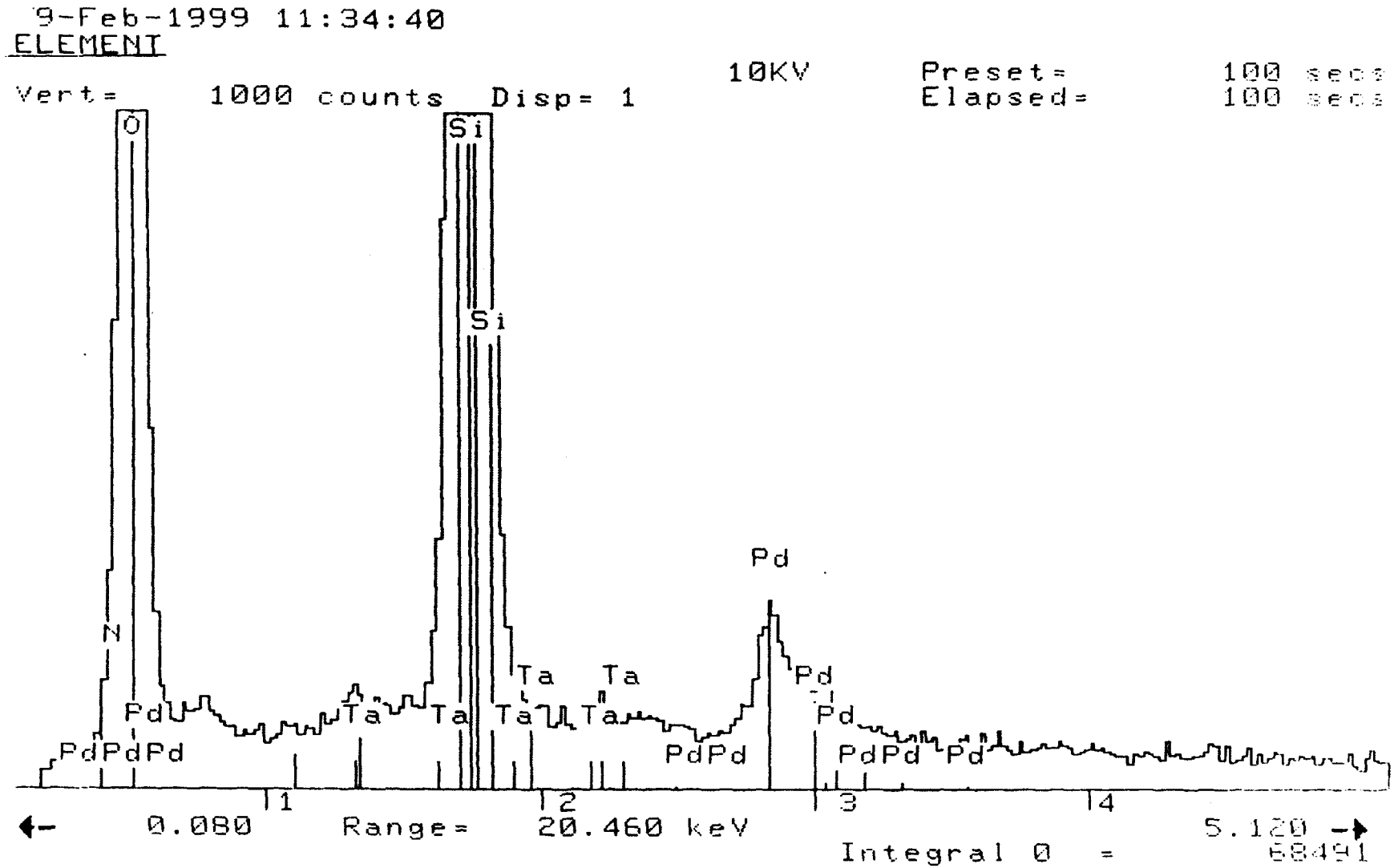

HYPOTHESIS

- When burn-in was performed on hermetically sealed filters at +125ºC, hydrogen was desorbed out of the Kovar carriers, epoxy and plated parts and into the air inside each hybrid MIC module.
- A catalytic reaction between the hydrogen and the palladium in the 35k ohm Tantalum Nitride resistors subsequently resulted in slight shifts in their resistance values.
- Due to the design of the analog section, these slight shifts resulted in very large changes in the static output frequency of the filter module channels.

SUPPORTING DATA

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- Final RGA test: 1776ppm Hydrogen, 97.8% Nitrogen, 1.57% Moisture
- Electron Dispersion X-Ray Detector (EDAX) identified Palladium in Tantalum Nitride resistor films.

POST 96 HOUR BAKE RGA DATA

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Hydrogen	0.1775% (1776 PPM)
Nitrogen	97.8073%
Moisture	1.5681% (pass, <5%)
Oxygen	0.2258% (2258 PPM)
Carbon Dioxide	0.1397% (1397 PPM)
Argon	0.0218% (218 PPM)
MEK	0.0540% (540 PPM)
Hydrocarbon	0.0057% (57 PPM)

DRY AIR

Nitrogen (N2)	78.09%	
Oxygen (O2)	20.95%	
Argon	0.93%	
CO2	0.03%	
Neon	0.0018%	
Helium	0.00052%	
Methane (CH4)	0.00011%	
Krypton	0.0001%	
Hydrogen (H2)	**0.00005%**	**(0.5 PPM)**
Ozone (O3)	≤0.00005%	
Xenon	0.0000087%	
CO	≤0.00005%	
N2O	0.0000003%	
SO2	≥0.0000007%	

Nitric Oxide, Nitrogen Dioxide, Formaldehyde, Ammonia (NH3)

INITIAL RGA TEST DATA

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GAS DETECTED	MODULE 1	MODULE 2
Hydrogen	**0.4036%** (4036ppm)	**0.1930%** (1930ppm)
Nitrogen	65.7737%	77.6249%
Helium	23.6097%	7.7489%
Moisture	**7.9643%**	**6.7730%**
CO2	1.8147%	1.4550%
Oxygen	2747ppm	5.7011%
MEK	886ppm	779ppm
Argon	248ppm	3933ppm

Other: Hydrocarbon, Krypton, THF (all <156ppm)

X-RAY EDS OF RESISTOR CHIP IN HYBRID

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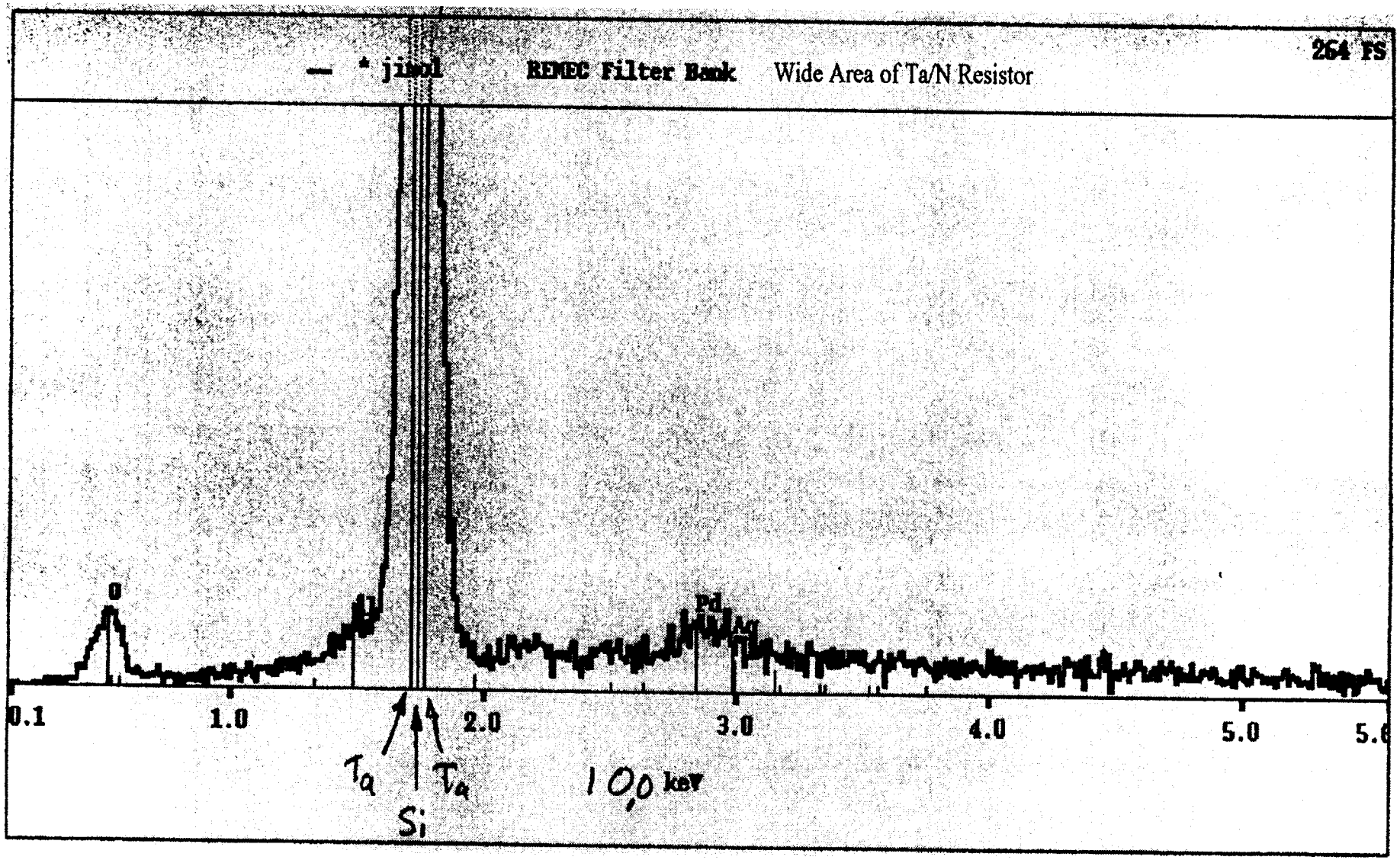

SOURCES OF HYDROGEN

- Ferrous Metal Package Materials, trapped in metal at structural imperfections, grain boundaries, precipitate interfaces, dislocation cores. (Cold Rolled Steel, Kovar, Invar)
- Gold and Nickel Plating Process.
- Microwave Absorbers (powdered iron filings suspended in a carrier such as silicone rubber)
- Epoxy is suspected as a source.
- Capacitors, Circulators, Isolators, Ferrite Pucks, Circuit Substrates, Resistors and Metal Films may be sources.

SIGNIFICANT INFORMATION

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- Research theory assumes a catalytic reaction with Palladium and molecular Hydrogen forming mono atomic hydrogen. In GaAs Semiconductors this results in compensation of donors in the channel or a shift in barrier height.
- A 10 to 20 ohm delta shift in resistance value between the two 35k ohm tantalum nitride resistors will result in the observed output drift.
- Modifications as a result of this study, using a center tapped dual tantalum nitride resistor, replacement of Kovar carrier with molybdenum, improved electrical grounding, proper 24 hour pre-seal vacuum bake and the addition of a hydrogen getter.
- Static output frequency has stabilized by a factor >100 times and there is no longer any frequency drift during burn-in testing of the hermetic cavity.

CORRECTIVE ACTION

- Change Kovar carriers to Copper-Molybdenum.
- Add Hydrogen Getter from Allied Signal Aerospace (HMC Getter) which can maintain hydrogen levels to <1 PPM and the dew point <-100ºC
- Open package thermal treatment bake-out at 100 to 110ºC.
- Perform 24 hour Vacuum Bake at +85ºC prior to welding cover over module in a dry Nitrogen/Helium gas environment.
- Lower Burn-In temperature to +85ºC.
- Replace the two 35k ohm single chip Tantalum Nitride resistors with a dual center tap resistor.
- Locate resistors from a supplier that does not use Palladium in their process.
- Maintain hybrid module temperature below +85ºC during all post seal process and screening tests.

SUMMARY

- Isolated Failure Mechanism
- Developed a Hypothesis
- Supported Hypothesis
- Modified Hybrid Design in Accordance With Hypothesis and Other Problems With Circuit.
- Demonstrated new circuit design was now stable.
- Identified new concern with tantalum nitride chip resistors for hydrogen desorbed inside a hermetic microelectronic hybrid device.