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Qualification Test Results on Si MMIC (use NESAT4 Process)

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1. Introduction

In the fields of communication systems and consumer electronics (e.g.CATV receivers, SHF broadcasting reseivers and BS/CS tuners), analog and degital ICs from UHF to microwave frequency range are widely used. These analog and degital ICs are required for compactness, economy and high reliability.

To respond to above described requirment, NEC has developed many Kinds of Si-monolithic microwave ICs.

In this report, the device structure and the results of the reliability qualification tests on Si MMICs are described.

Qualification tests have been performed for the MMIC and the MMIC elements such as transistor, resistor and capacitor.

2. Device structure

Fig.1~Fig.3 show the cross sectional view transistor cell, capacitor and resistor. The MNS(Metal Nitride Semiconductor) sturcture is adoped in capacitors.

The resistors are formed by polysilicon.

The features of transistor cell are described below:

(1) An optimal epitaxial layer grown by VPE(Vapour Phased Epitaxy).

(2) Oxide isolation to reduce parasitic capacitance.

(3) A shallow and higher impurity doped base by ion implantation. A shallow emitter by diffusion from As-doped polysilicon.

(4) An emitter of 0.5 μ m width processed by photo lithograph.

(5) A nitride passivation film.

(6) A Ti-Pt-Au electrode structure.

3. Qualification Tests

(1) Qualification Tests on Basic Element.

Design rules for ICs are qualified by performing qualification test on each basic elements consisting of IC such as transistor, capacitor and resistor.

A series of qualification tests on basic elements consist of following items:

(a) High temperature storage tests at Ta=259℃,295 and 337℃ on transistor and resistor.

(b) High temperature DC bias test at Tj=200℃ on capacitor.

(2) Qualification Tests on IC

Qualification tests of ICs are performed on typical types of each family classified by integration level, function, structure and production technique applied.

A series of qualification tests on IC consist of following items:

(a) Environmental tests (Thermal and Mechanical).

(b) Radiation hardness.

(c) Solderability strength.

(d) High temperature storage tests at Ta=200℃.

(e) High temperature DC bias tests at Tj=200℃.

Test conditions and sample size of the qualification tests are shown Table 1.

The delta parameters and criteria are shown in Table 2-1 and Table 2-2.

4. Test results and Discussions

Basic element

(1) Transistor

The summary of qualification test results are presented at Table 3.

High temperature storage test

High temperature storage test at Ta=259℃,295℃ and 337℃ were performed using 10 samples. The test results are shown Table 4.

At the high temperature stress level(Ta=337℃), the samples have started to fail from 100 hours. The failure mode is h_{FE} degradation.

This is caused by diffusion of Au into Si due to degradation of Pt as barrier .

The Arrhenius plots on the tests are shown in Fig. 4, using $\triangle Ea$=1.8eV that has been confirmed at Au electrode microwave Si transistor.

From this plot, the estimated MTF for transistor at Tj=100℃ is 3.0×10^{11} hours.

(2) Resistor Element

Poly silicon Resistor

High temperature storage tests at Ta=259℃, 295℃ and 337℃ were performed using 10 samples for 3000 hours.

The test results are shown Table 5. The Arrhenius plots on the test are shown in Fig. 4. This Arrhenius plot gives the activation energy of 1.8eV. From this plot, the estimated MTF for polysilcon Resistor at Ta=100℃ is 3.0×10^{11} hours.

(3) Capacitor

Biased test on 10 MNS capacitors has been performed with condition of 6V at Ta=200℃ for 5000 hours.

The test results are shown at Table 6.

No failure was observed.

Consequently, each basic element is considered to be sufficiently reliable for constructing MMICs.

Si MMIC

Qualification test have performed for prescaler IC μPB1509B as the typical of the family which are classified by process and structure of wafer fabrication.

① High Temperature storage test

High temperature storage test at Ta=200℃ was performed for μPB1509B using 20 samples.

This test was performed for 5000 hours. The test results are shown Table 7. No failure has been observed for 5000 hours.

② High Temperature DC bias test

High temperature DC bias test at Tj=200℃ was performed for μPB1509B using 100 samples.

This test was performed for 5000 hours. The test results are shown Table 8. No failure has been observed for 5000 hours.

△Icc and △Pout changes are shown in Fig. 5.

Any significant variation of the two parameters has not been observed during 5000 hours at Tj=200℃.

If one device was failed at the test period of 5000 hours at Tj=200℃, the MTF of △Icc or △Pout line were drawn in Fig. 6, using △Ea=1.8eV, which is confirmed by the results of Au electrode microwave Si transistor. MTF at Tj=100℃ is estimated to be over 1×10^9 hours.

③ Thermal and Mechanical Environmental Test and Solderability Strength.

As shown Table 3, no failure was obserbed with respect to thermal envionmental test, mechanical environmental test and solderability strength.

④ Radiation Hardness

Gamma-ray irradiation test was carried out for prescaler IC μPB1509B.

Dose rate is 1×10^5 and 1×10^6 rad/hour.

The test results are shown Table 3. No failure was observed with respect to this test. Consequently, it was confirmed that the Si MMICs are sufficiently tough from the view point of radiation hardness.

5. Conclusion

Accelerated life test have been performed on prescaler, their Tr, resistor and capacitor. MTF at Tj=100℃ is estimated to be over 1×10^9 hours.

Radiation Hardness tests have been carried out on prescaler. No degradation was observed up to 1×10^6 rad gamma ray irradiation.

It has confirmed that the Si MMICs are sufficiently reliable for practical applications.

Table 1 Test Item and Test Conditions

Test Item	Test Condition	Sample Size			
		IC	Basic Element		
			Transistor	Resistor	Capacitor
Environmental Test (Thermal)	a) Soldering Heat 260℃, 10sec b) Temperature Cycling -65℃～+25℃～+175℃, 100Cycles (MIL-STD-883 Method 1010) c) Thermal Shock 0℃～+100℃, 100Cycles (MIL-STD-883 Method 1011) d) Hermetic Seal Test (MIL-STD-883 Method 1014 Test Condition A2 and C)	20	—	—	—
Environmental Test (Mechanical)	a) Shock 1,500G, 0.5ms (MIL-STD-883 Method 2002) b) Vibration,Variable Frequency 100～2,000Hz, 20G, 3 axis, 4 min (MIL-STD-883 Method 2007) c) Constant Acceleration 20,000G, 3 axis, 1 min (MIL-STD-883 Method 2001) d) Hermetic Seal Test (MIL-STD-883 Method 1014 Test Condition A2 and C)	20	—	—	—
Radiation Hardness	10^5 rad by Cobalt 60 10^6 rad by Cobalt 60 (Non Bias)	5	—	—	—
Solderability Strength	245℃, 5 sec (MIL-STD-883 Method 2003)	10	—	—	—

Test Item and Test Conditions (Continued from Table 1)

Test Item	Test Condition	Sample Size			
			Basic Element		
		IC	Transistor	Resistor	Capacitor
High Temperature Storage Test	a) Ta=200℃	20	—	—	—
	b) Ta=259℃	—	10	10	—
	c) Ta=295℃	—	10	10	—
	d) Ta=337℃	—	10	10	—
	5,000 hours or up to F(t)＞50%				
High Temperature DC Bias Test	a) Tj=175℃	—	—	—	—
	b) Tj=200℃	100	—	—	10

Table 2-1 Delta Parameters and Criteria of Basic Elements

a) Transistor Element

Parameter	Symbol	Test Condition	Delta Criteria
Collector Cut-off Current	I_{CBO}	V_{CB}=10V	+100nA or +100% Whichever is greater
Emitter Cut-off Current	I_{EBO}	V_{EB}=1.5V	+100nA or +100% Whichever is greater
DC forward Current Gain	h_{FE}	V_{CE}=2.5V I_C=1mA	±15%

b) Resistor Element

Parameter	Symbol	Test Condition	Delta Criteria
Resistance	R	V=0.5V	±5%

c) Capacitor Element

Parameter	Symbol	Test Condition	Delta Criteria
Capacitance	C	freq.=1MHz nonbias	±10%

Table 2-2 Delta Parameters and Criteria of Si MMIC

d) μ PB1509B

Parameter	Symbol	Test Condition	Delta Criteria
Supply Current	Icc	V_{CC}=3V No Signal input	±15%
Power Output	Pout	V_{CC}=V_{S1}=V_{S2}=2.2V Pin=-10dBm fin=200MHz	±1dBm

Table 3 Summary of Qualification Test Results

Test Item	Test Condition	Results (Failure/Sample)				Reference Figure or Table
		IC	Basic Elements			
		μPB1509B	Transistor	Poly Silicon Resistor	Capacitor	
Environmental Test (Thermal)	a) Soldering Heat b) Temperature Cycling c) Thermal Shock d) Hermetic Seal Test	0/20	—	—	—	—
Environmental Test (Mechanical)	a) Shock b) Vibration, Variable Frequency c) Constant Acceleration d) Hermetic Seal Test	0/20	—	—	—	—
Radiation Hardness	10^5 rad 10^6 rad by Cobalt 60	0/5	—	—	—	—
Solderability	a) 245℃, 5 sec	0/10	—	—	—	—
Strength						
High Temperature Storage Test	a) Ta=200℃	5000 Hours 0/20	—	—	—	Fig.4 Table 4, 5 and 7
	b) Ta=259℃	—	2000 Hours 0/10	3000 Hours 0/10	—	
	c) Ta=295℃	—	2000 Hours 7/10	3000 Hours 7/10	—	
	d) Ta=337℃	—	300 Hours 10/10	1000 Hours 10/10	—	

Summary of Qualification Test Results (Continued from Table 3)

Test Item	Test Condition	Results (Failure/Sample)				Reference Figure or Table
		IC	Basic Elements			
		μ PB1509B	Transistor	Poly Silicon Resistor	Capacitor	
High Temperature DC Bias Test	a) Tj=175℃	—	—	—	—	Fig.6 and 7
	b) Tj=200℃	5000 Hours 0/100	—	—	5000 Hours 0/10	Table 6 and 8

Table 4 High Temperature Storage Test of Transistor Element

Test Condition	Quantity	Number of Failures								
		0	72	144	240	400	650	1000	2000	Hours
Ta=259℃	10	0	0	0	0	0	0	0	0	—
Ta=295℃	10	0	0	0	0	0	0	3*	8*	—
Ta=337℃	10	0	3	7*	9*	9*	10*	—	—	—

*h_{FE} degradation

Table 5 High Temperature Storage Test of Resistor Element

Poly Silicon Resistor

Test Condition	Quantity	Number of Failures										
		0	50	100	300	500	1000	1500	2000	2500	3000	Hours
Ta=259℃	10	0	0	0	0	0	0	0	0	0	0	—
Ta=295℃	10	0	0	0	0	0	1	3	5	5	7	—
Ta=337℃	10	0	0	2	5	7	10	—	—	—	—	—

Table 6 High Temperature DC Bias Test of Capacitor

Test Condition	Quantity	Number of Failures						
		0	200	500	1000	3000	5000	Hours
Tj=200℃	10	0	0	0	0	0	0	—

Table 7 High Temperature Storage Test of Si MMIC

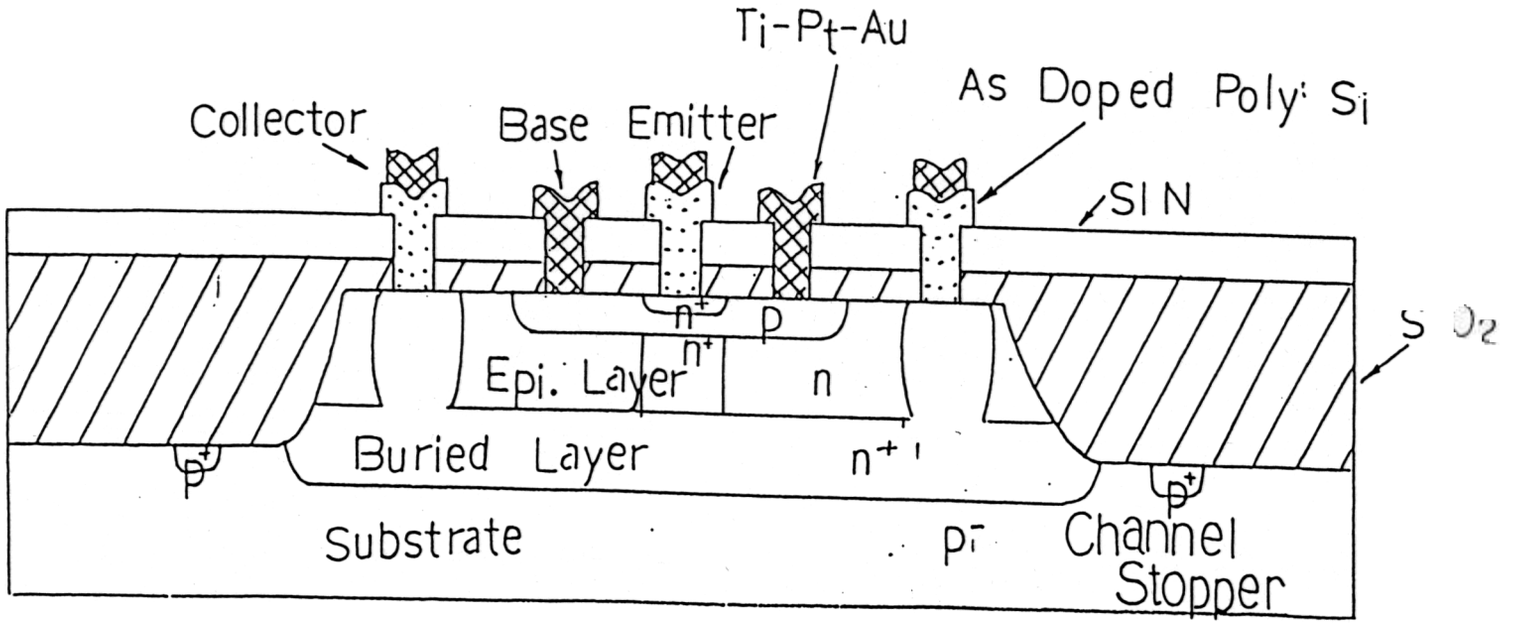
Test Condition	Quantity	Number of Failures						
		0	168	500	1000	1500	3000	Hours
μPB1509B	20	0	0	0	0	0	0	—

Test Condition Ta=200℃

Table 8 High Temperature DC Bias Test of Si MMIC

Test Condition	Quantity	Number of Failures						
		0	168	500	1000	1500	5000	Hours
μPB1509B	100	0	0	0	0	0	0	—

Test Condition Tj=200℃



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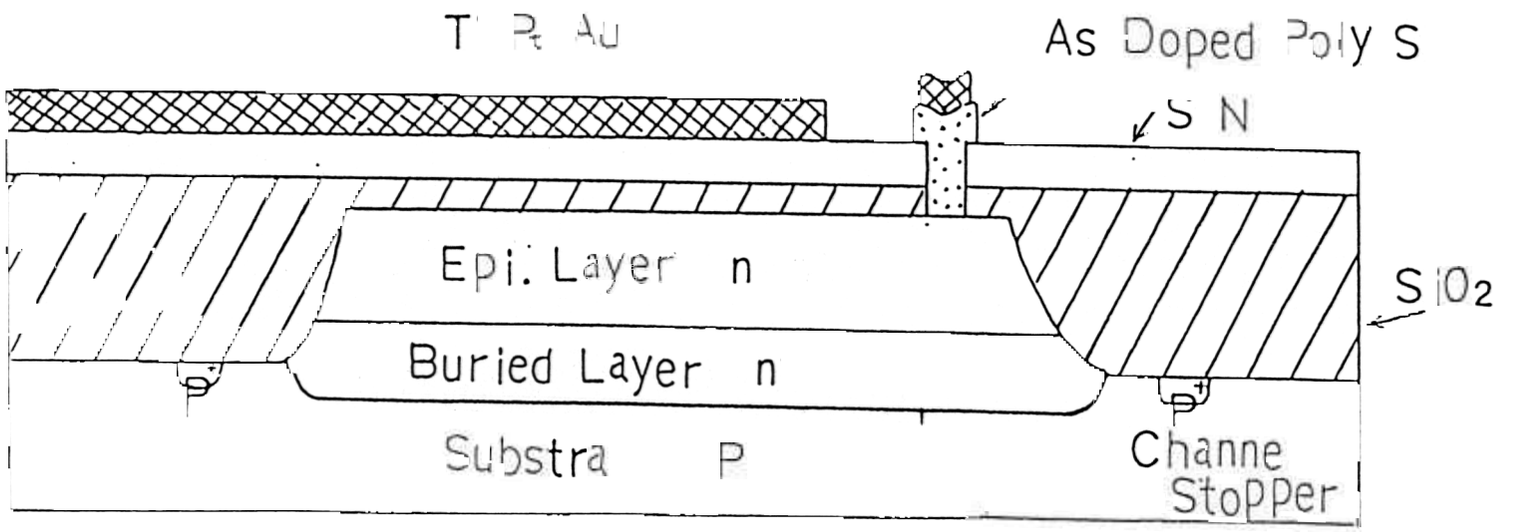
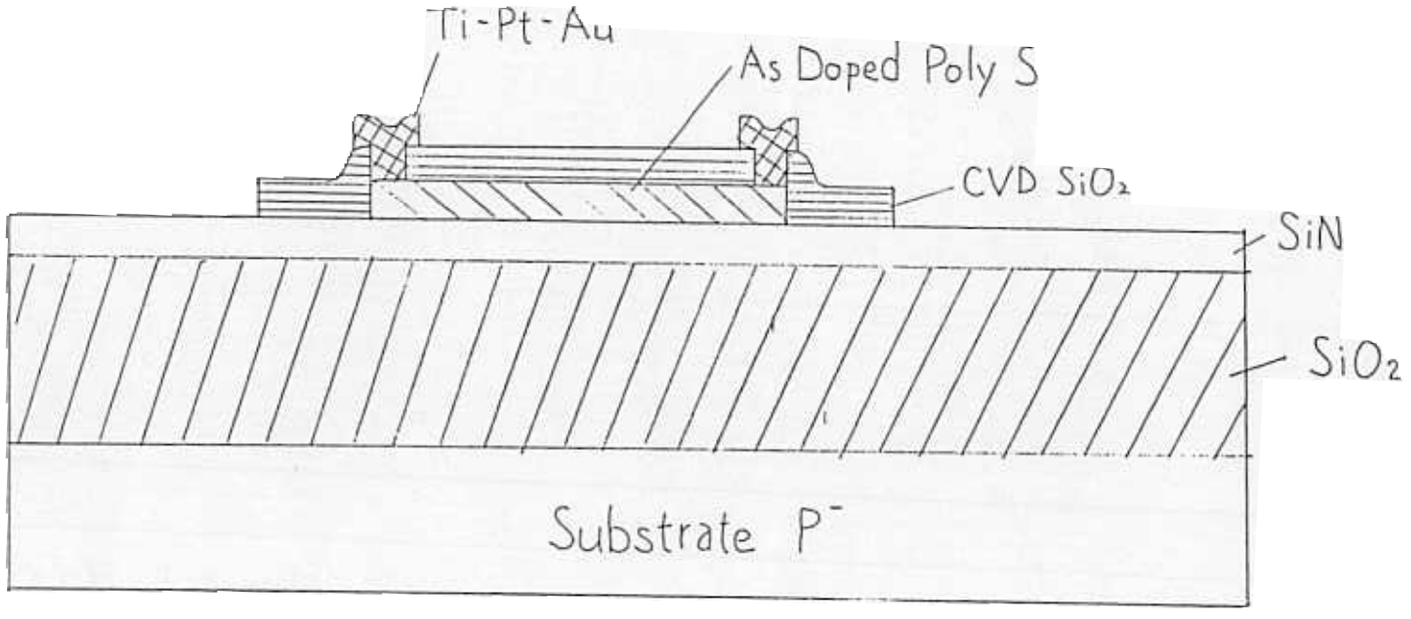
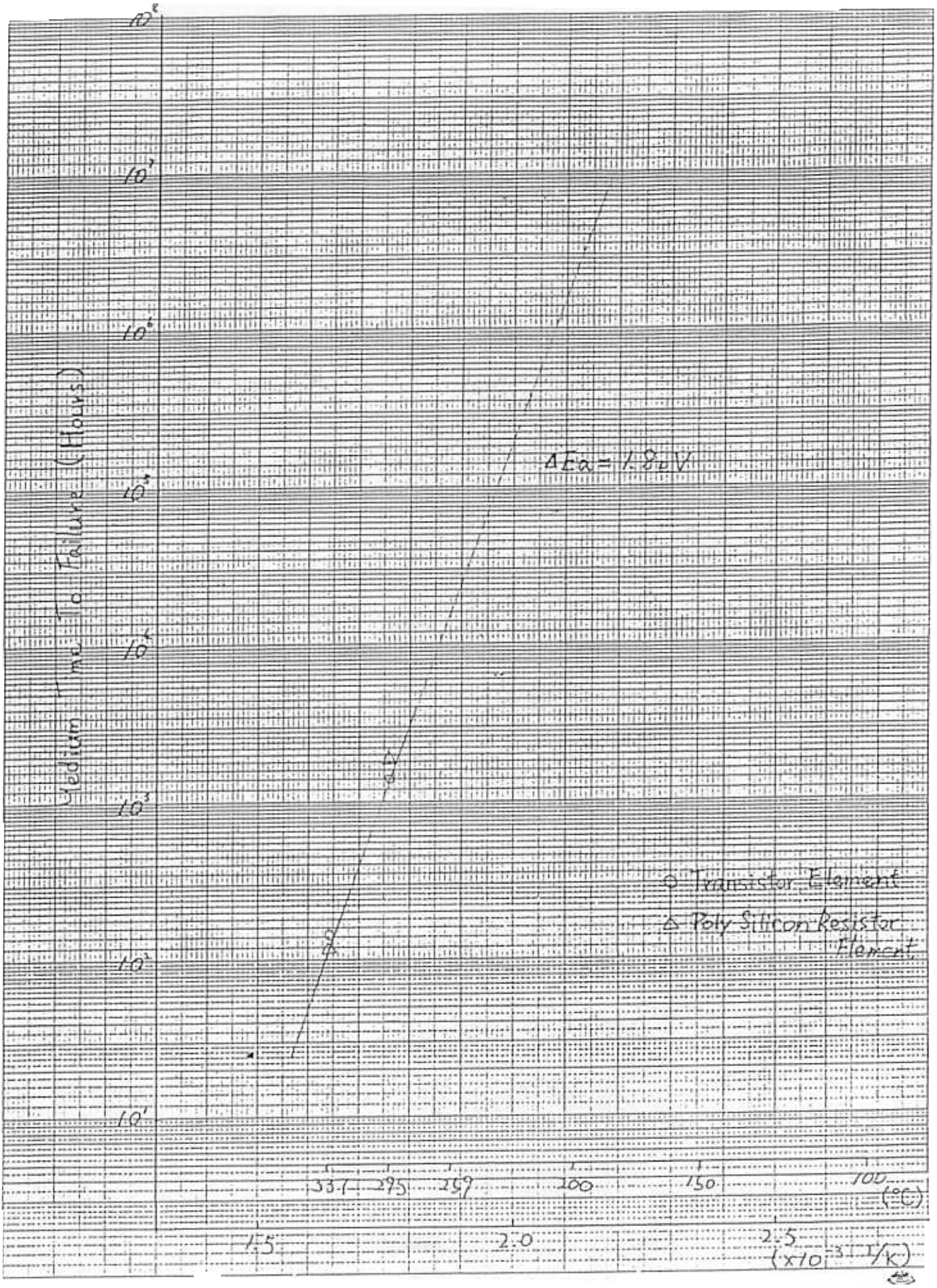


F G A CAPAC TOR CR SS ECT ONAL V E



F G 3 A RES STOR CRO S SECT ONAL E'

G ARRHE US PL T OF BAS C ELEMENT



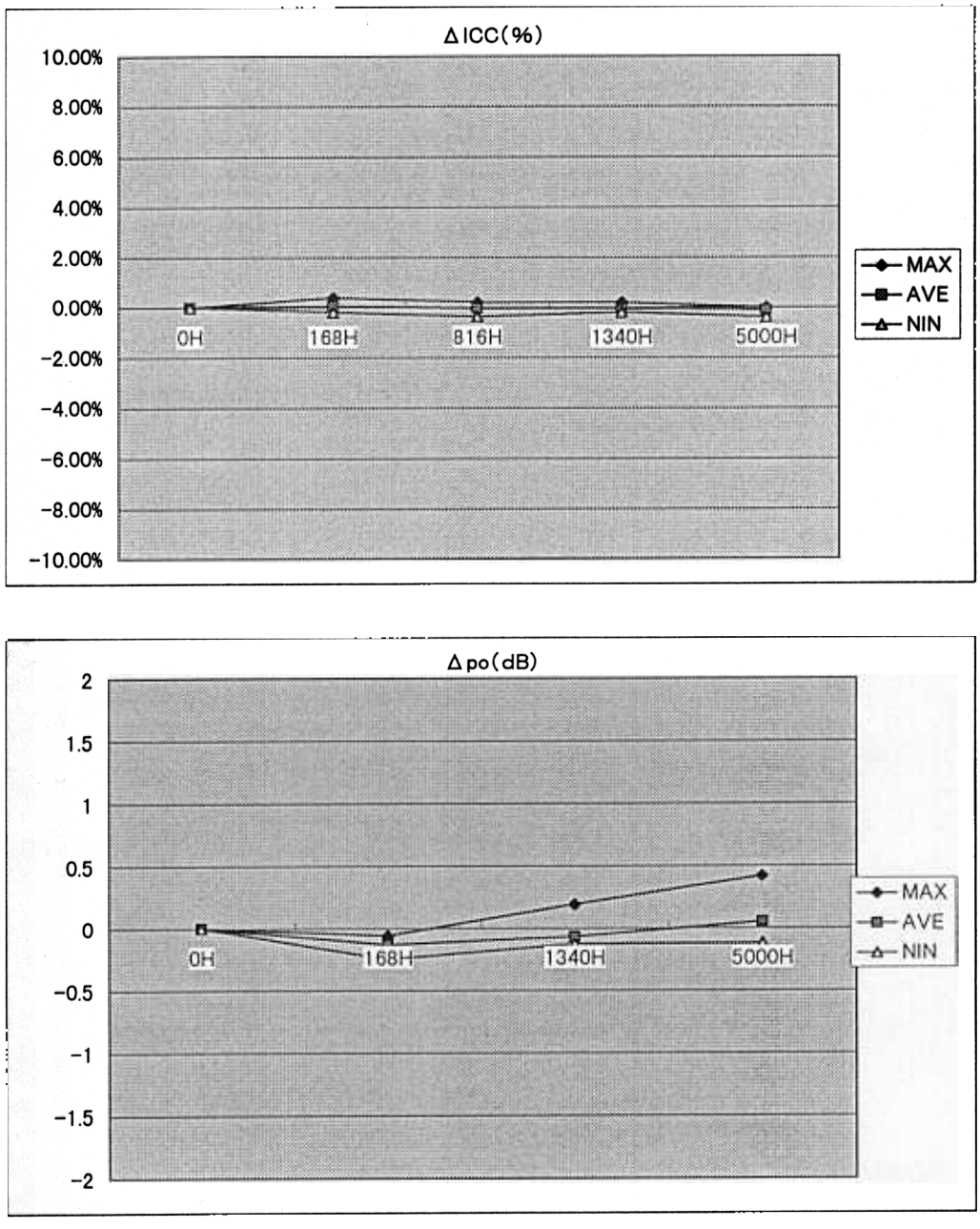


Fig. 5 μPB1509B PARAMETER CHANGES ON HIGH TEMPERATURE DC BIAS TEST

Fig.6 ARRHNIUS PLOT OF PRESCALER ON HIGH TEMPERATURE DC BIAS TEST