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ASD INTERIM REPORT 7-865 (VI)
November 1962

SILICON SEMICONDUCTOR NETWORKS MANUFACTURING METHODS

J.W. Lathrop
W.C. Brower

Texas Instruments Incorporated
Semiconductor-Components Division
Dallas, Texas

Contract No. AF 33(600)-42210
ASD Project 7-865

Interim Technical Engineering Report
January-March 1962

Design and development of machines for fabrication and assembly of functional electronic blocks are progressing well.

Electronics Branch
Manufacturing Technology Laboratory

Aeronautical Systems Division
United States Air Force
Wright-Patterson Air Force Base, Ohio

ABSTRACT-SUMMARY
Interim Technical Progress Report

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During this reporting period, the process studies, per se, were concluded. Techniques have been developed for evaluation of all diffusion parameters.

All machines for the pilot line are either completed, being constructed or modified, or in advanced design stage. The philosophy guiding creation of these machines is that all possible operations will be performed on the functional electronic blocks while they are still in slice form. These operaations include cleaning, polishing, photoresist applications, etching, diffusion, and application of evaporated leads and contacts.

Considerable progress has been made toward perfecting a welded package.

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FOREWORD

This Interim Technical Progress Report covers the work performed under contract AF 33(600)-42210 from 1 January through 31 March 1962. It is published for technical information only and does not necessarily represent the recommendations, conclusions, or approval of the Air Force.

This contract with the Semiconductor-Components Division of Texas Instruments Incorporated was initiated under Manufacturing Methods Project No. 7-865, "Silicon Semiconductor Solid Circuits." It is under the technical direction of Mr. Paul Poliquin of the Electronics Branch, Manufacturing Technology Laboratory, Directorate of Materials and Processes of the Aeronautical Systems Division. Assistance is furnished by Captain Lawrence Roesler, Molecular Electronics Branch, Electronic Technology Laboratory of the Aeronautical Systems Division.

The Manufacturing Methods program and related contracts for research and development, manufacturing techniques, and application of semiconductor networks to equipments are administered by Charles H. Phipps, Program Manager, Integrated Circuits Group, Texas Instruments Incorporated. The work performed during this report period was under the supervision of Dr. Jay W. Lathrop and William C. Brower, Semiconductor Networks Department, Semiconductor-Components Division.

The primary objective of the Air Force Manufacturing Methods program is to develop new manufacturing techniques and demonstrator equipment, thereby making reliable semiconductor networks (functional electronic blocks/molecular electronics) available in quantity for application to future equipments.

The words "semiconductor networks" are used by Texas Instruments to describe the type of product with which this program is concerned, whereas the terms "functional electronic blocks" and "molecular electronics" are frequently used by the Air Force. The term "SOLID CIRCUIT" is reserved by Texas Instruments as a trademark for this type of product.

Approved by Charles H Phipps
CHARLES H. PHIPPS
Program Manager

Approved by Jack Kilby
JACK KILBY
Manager, Semiconductor Networks
Department

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SECTION I

INTRODUCTION

1.1 Objectives and Scope

The objectives of contract AF 33(600)-42210 are twofold:

a. To establish production processes and techniques for manufacture of semiconductor networks

b. To establish production techniques for the assembly of equipment utilizing semiconductor networks.

The semiconductor networks fabricated under this program are representative of the current state of the art, and capable of performing a variety of circuit functions. This program is complementary to the investigations of design techniques for semiconductor networks under contract number AF 33(616)-6600, connection techniques under contract number AF 33(616)-8133, and several programs for the design of specific semiconductor networks.

1.2 Program Status

During this reporting period, process studies were concluded with the successful development of basic techniques for production fabrication of semiconductor network devices. Major effort consisted of process investigations for adaptation of these techniques to machine operations, and design and construction of semiautomatic machinery to carry out the required procedures. Equipment designs emphasized the production of semiconductor materials in slice form in the areas of materials preparation, diffusion, and photoetching of silicon oxide and aluminum layers.

Machines now in design or under construction are all scheduled for completion and installation on the pilot production line, which will be operated in July, 1962, to demonstrate the capability of producing 500 good semiconductor network devices per day.

Progress was made on developing a weldable network package for improved reliability.

SECTION II

PROCESS STUDIES

2.1 General

Process development work for the pilot line has been completed, and continuing investigations are no longer being charged to this contract. The following work was done in completing the process development study.

2.2 Diffusion

2.2.1 Diffusion Evaluation

Curves were prepared relating the reciprocal sheet-resistance, junction-depth product to the surface concentration of a diffused layer with a Gaussian distribution on top of another diffused layer with a Gaussian distribution. The curves are for a p-type diffusion on an n-type diffusion with diffusion parameters similar to the Series 51 base and collector diffusions respectively. A comparison of these curves with those calculated by Irwin of Bell Telephone Laboratories for diffusion into a uniformly doped substrate (not published but in wide use at Texas Instruments) shows that the surface concentration of a base diffusion can be determined to within a few percent by using Irwin's curves and ignoring collector diffusion.

An expression has been devised for calculating the sheet resistance of the diffused region corresponding to the base of a transistor under an emitter diffusion. This region is of interest because of the high sheet resistances obtainable (on the order of megohms per square). A report covering this work is included in the Appendix.

2.2.2 Thermally Grown Lead-Glass Films

Thin films of lead glass have been grown on polished silicon slices by heating in an atmosphere containing lead and oxygen. Linear growth rates of 1350 angstroms per hour at 650°C and 3100 angstroms per hour at 700°C have been observed. It has been possible to increase the thickness and change the composition of a previously grown silicon dioxide film by heat treatment in the lead atmosphere. An increase in the thickness of a lead-glass film (accompanied by a consumption of silicon) has also been observed during subsequent high-temperature heat treatment in air. It is hoped that a thermally grown silicon dioxide film converted to a thicker lead-glass film may, because of the volume increase, have fewer pinholes and hence may be more suitable as a dielectric film for capacitors or as an insulating substrate for evaporated leads.

2.2.3 New Diffusion Techniques

Efforts have been made to obtain uniform, low-concentration, p-type diffusions for field-effect channels. Reasonable uniformity has been obtained using a closed platinum box with a boron anhydride (B_2O_3) source. Although uniformity was obtained in the first runs, the boron concentration was too high for suitable field-effect channels. Lowering the deposition temperature, however, tended to decrease the uniformity.

A test was made to determine the extent to which the boron concentration could be lowered by impurity trapping by the oxide during a low-temperature oxidation. Methyl borate was used as the source. Although relatively low concentrations were obtained, there was considerable nonuniformity.

It was felt that a combination of the box deposition technique with a low-temperature oxidation-trapping step would yield more uniform, low-concentration diffusion. Field-effect devices have been made using this combination with promising results.

2.2.4 Reproducibility

Data on collector diffusion from ten lots in production was analyzed and the following was found.

> Seventy percent of the sheet resistivity readings were within 20 percent of the mean.
>
> Thirty-nine percent of the sheet resistivity readings were within 10 percent of the mean.

This degree of reproducibility should be satisfactory for production of standard-tolerance network designs.

2.3 Vacuum Technology

2.3.1 Electron-Beam Evaporation

Some silicon carbide evaporations were made for consideration as a potential dielectric as well as an insulating film. The best capacitors made yielded 0.18 picofarad per square mil with a breakdown voltage of 30 volts. However, most had a capacitance of 0.1 picofarad per square mil with a breakdown voltage of 20 volts. The material looked more promising as an insulator, as 0.03 picofarad per square mil was obtained for films with a breakdown voltage greater than 650 volts. No thickness measurements have been made on these films.

Electron-beam-evaporated Kanthal D. R. was studied in some detail as a thin-film resistor material for incorporation in semiconductor networks. An attempt to heat-treat the resistive films at 600° C failed, as the aluminum contacts separated from the Kanthal and an oxide film appeared to form on the resistors, preventing measurement of the resistance by probing.

The heat treatment was repeated in the same furnace with a series of new samples at 350° C. In both heat treatments, a helium atmosphere was used. The samples after heat treatment had resistances some 50 percent below their initial values, but showed no better aging stability than the non-heat-treated control group. T. C. R. measurements were made on two heat-treated samples over the range 0-350° C. These showed a T. C. R. of approximately 500 ppm per °C which should be compared to the 50 ppm per °C tentatively specified for the resistors.

It was felt that the 350° C heat treatment had not been effective and that heating in vacuum should be considered. One sample without aluminum contacts and one with them were heated to 500° C for 10 minutes in a vacuum. The resistors showed no trace of oxide film formation, and the contacts did not separate from the resistive film.

Spectrographic analysis of the Kanthal D. R. films showed no significant change when compared to the original material. This indicates, within the limits of accuracy of the analysis, that the electron-beam evaporation of the Kanthal D. R. does not cause severe fractionation of the components of the alloy. However, the original material etches very quickly in aqua regia, while the deposited film is attacked only very slowly.

2.3.2 Crystal Oscillator Film Thickness Monitor

A new crystal was purchased and lapped down to give an 8.8-kilocycle-per-second beat with the standard crystal. This should be compared to the 25-kilocycle-per-second beat obtained before. It is hoped that this lower frequency will give a more sensitive system, since the percentage change in frequency will be greater when the crystal is loaded. The crystal holder will be incorporated in the rotating work holder, electrically connected to the circuit through a slip-ring connector.

2.4 Assembly

2.4.1 Bonding

Bonding of 0.0007-inch aluminum wire, then alloying to contact areas on FEB devices was tried to permit electrical tests on pilot slices before contacts were made. Only one worked of three bonded and alloyed. This does not appear to be a promising technique.

2.4.2 Baking Procedures

Experiments to determine the effects of bake times, temperatures, and ambients on the electrical characteristics of devices were started. In this first test, a lot of multiple planar regular transistors (MPRT's) was split into three groups after contacts were made while still in slice form. Each group received one of three treatments: a 300° C nitrogen bake for 24 hours, a 300° C vacuum bake for 24 hours, or no bake. Unfortunately, no definite conclusions could be reached because of the initial spread in characteristics. In general, it did appear that baking was desirable.

SECTION III

METHOD INVESTIGATIONS

3.1 Pilot Production Line Layout

A layout drawing is nearly completed for the production line area to show the placement of all machines and operations required for a production line to produce 500 good network devices per day.

One bay will be occupied by two rooms housing the diffusion and photoresist operations. These are sealed "white rooms" that will be supplied with super-clean air to keep airborne contamination to a minimum. Considerable effort has gone into laying out equipment in the two rooms to permit efficient flow of material through the various slice-processing steps with very little personnel traffic. Material will be handled into, out of, and between the rooms by means of pass-through airlocks. The second bay in the manufacturing area will be devoted to vacuum evaporation and scribing, plus all the bar operations such as mounting, bonding, encapsulation, testing, and package manufacturing.

The darkroom, diffusion-room complex is designed to handle an input of 500 silicon slices per day and will employ semiautomatic equipment. The assembly or bar operations are largely manual and initially will not be completely balanced in capacity to this level.

Relocation of manufacturing facilities is planned to be completed by 1 June with all new machines installed and proven-in before July.

3.2 Photoresist Exposure Investigations

3.2.1 General

Experiments were conducted to determine some basic properties of Kodak Metal Etch Resist (KMER) to aid in design of projection exposure systems and to improve the speed and performance of present contact exposure methods. Information desired included

Minimum exposure time for KMER

Optimum light source

Degree of reciprocity failure exhibited by KMER similar to that shown by photographic emulsions

Spectral sensitivity (watts per unit area) versus wavelength relationship for KMER.

The approach taken was first to investigate several ultraviolet light sources to determine the most effective one for exposure of KMER. This best light source would then be used in further experiments on exposure parameters. Trials were run with standard KMER spin-coated silicon slices and a typical oxide-removal photomask pattern. Minimum exposure was determined by decreasing the time or increasing the source-to-slice distance until the pattern edges became fuzzy, since this edge effect usually occurred with insufficient illumination before larger exposed areas failed to develop properly.

3.2.2 Electronic-Flash Light Source

Investigations were conducted with an electronic-flash photographic light source for the rapid exposure of photoresist. An Ascorlight 200-watt-second flash gun was used to attempt instantaneous exposure instead of the 10 to 30 seconds time required with incandescent lamps. Tests showed that a single flash at 2 inches distance could expose the resist film, but the results on subsequent slices were erratic and varied between overexposure and underexposure. At greater distances, such as 7 inches, three flashes were required for exposure, but the long power-supply charging time between flashes gave this method no advantage.

An attempt was made to lengthen the approximately 600-microsecond light pulse produced by discharge of the capacitor into the zener flash lamp. A low-resistance inductance consisting of a 120-volt, 20-ampere Powerstat variable autotransformer was connected in series with the capacitor and lamp to lengthen the light pulse to several milliseconds. No apparent improvement was obtained.

A possible explanation for the failure to obtain satisfactory exposure with extremely short and intense light pulses is the reciprocity failure effect, which occurs because of the finite time required for the exposure reaction in most silver halide photosensitive emulsions. It is not known whether this effect applies to KMER, but previous independent attempts to expose KMER less than 10 seconds were not successful with any available light source.

One other explanation for the unsatisfactory results with electronic flash equipment is the optical arrangement, which consists of a relatively large spiral-coil lamp mounted in a reflector to give illumination over a large area for photographic purposes. The light rays are widely divergent rather than focussed on the photomask at short distances and are not efficiently utilized. For maximum sharpness, the rays should be collimated or should originate from a point source.

3.2.3 Quartz, Iodine-Filled, Tungsten-Filament Lamp

Tests were run with a quartz, iodine-filled, tungsten-filament lamp of 750 watts placed at varying distances from resist-coated slices in a mask fixture. For each exposure interval, the lamp-to-slice distance was increased until the threshold of insufficient illumination was reached. For this small-diameter source, it was assumed that light intensity was inversely proportional to the square of the distance. In this manner, the relationship between exposure time and intensity was obtained, which showed that these two factors are inversely proportional for KMER, as expected. Minimum exposure time for the iodine-tungsten lamp was 10 seconds. This was the fastest exposure found for any incandescent lamp source tried. The improvement over conventional tungsten projection lamps was attributed to the higher filament temperature and the quartz envelope, both of which produced greater ultraviolet radiation.

3.2.4 Mercury-Arc Lamp

The tests were repeated using a mercury-arc reflector spotlamp (GE No. H4G5). This source also gave an inversely proportional relationship between exposure time and intensity, but the 4-3/4-inch-diameter built-in reflector increased the light intensity at the point of focus to the extent that minimum exposure times as short as 1/5 second were obtained. Slightly longer times, around 1/2 second, were found to give uniform and noncritical exposure of KMER for production use.

3.2.5 Conclusions

The conclusions reached from these experiments were

> KMER can be exposed reliably at 1/5 second with practical, inexpensive light sources. This accomplishment has changed the design objectives for the production lighthouses, which are now being designed to use one alignment fixture that slides under a mercury-arc lamp for rapid exposure instead of two fixtures on a turn-around arm for simultaneous alignment and exposure.
>
> A mercury arc appears to be the most suitable light source for KMER because of its convenient operation and strong output in the ultraviolet region below 4000 angstroms. Minimum exposure time requires close spacing between lamp and work for sufficient intensity, and therefore indicates the need for a point source or collimated light for fine resolution. The GE mercury-arc reflector spotlamp provides sufficiently concentrated and collimated light for use in present designs, but further investigations are in progress on short-gap, high-pressure mercury-arc sources in larger sizes.
>
> Reciprocity failure was not observed for exposure times as short as 1/5 second, but exposure at 1/1700 second with electronic flash sources was not successful. Further experiments between these two time intervals will depend on obtaining higher-intensity sources so that exposure times below 1/10 second may be evaluated.
>
> The mercury-arc reflector spotlamp appears suitable for use in investigation of spectral sensitivity of KMER. Special ultraviolet filters have been ordered for this purpose.

3.2.6 Photomask Projection System

Work is progressing in the Electro-Optics Branch of the Apparatus Division's Missile and Space Department on an optical projection system for photoresist exposure. The project has been broken into the following steps:

Pick the long-wavelength cutoff region at which KMER begins to fail to react for reproduction purposes.

Pick the general region of suitable KMER reaction which is the optimum region for which to design the projecting lens system.

Design an optical projecting system with desired magnifying power so that by filter interchange a conversion from the chosen region may be made while maintaining a constant object-to-image distance.

Design an ultraviolet illumination system to provide sufficiently high intensity for projection of a 1-inch-square pattern mask.

Introduce a beam-splitter for viewing the image projected on the wafer.

Package the system for ease of operation with set mode for filter interchange, pattern and wafer placement.

Limit the variable adjustment during operation to visual alignment of the pattern projected on the wafer.

Consider magnifying the projected pattern and wafer for ease of alignment.

Equipment and materials have been acquired for tests of KMER spectral response using ultraviolet filters. Measurements of the refractive indices of optical materials in the ultraviolet region show that rapid changes occur with changing wavelength. This effect means that special lenses for projection will be required.

3.3 Darkroom

An expanded darkroom is being designed to house the photresist processing equipment. It will have a super-clean atmosphere and closely controlled humidity and illumination. Layouts have been made to show the application, baking, exposure and development of photoresist operations performed on machines located along a continuous conveyor which carries the work to and from each operation. A similar conveyor system feeds the oxide, aluminum, and gold etch-removal operations on a parallel connected assembly line.

3.4 Aluminum-Removal Etching

Aluminum contacts and leads are formed by etch-removal of areas not protected by a photoresist pattern. A sodium hydroxide solution is usually used as the aluminum etchant. A prototype machine was designed and completed to remove aluminum by spray etching, but its capacity was not as great as planned, and process changes made it desirable to develop an improved machine to remove aluminum, wash the slices and remove the protective photoresist film in one operation. The speed of aluminum etching is considerably increased at elevated solution temperatures, and preliminary investigations were therefore directed toward methods of hot-etching plus elimination of the hydrogen bubbles that produce uneven removal.

The prototype machine required approximately four minutes of etching time per slice. It was equipped with a single, fixed spray-head and an etchant heater, but the wide-angle spray required for uniform slice coverage greatly reduced the effective etch temperature at the slice surface and thereby increased etch time.

Under-liquid jet etching was evaluated as a method for maintaining better temperature control than air spraying allows. In this method, a gear pump recirculates the etch solution through a submerged spray nozzle against the aluminum-coated slice, which is also beneath the liquid. Tests were run with etch concentration, etch temperature, etch time, and spray-head-to-slice spacing as variables. Best results were obtained with a temperature of 48°C, etchant concentration of 20 percent, time of 36 seconds, and a spacing of 3/4 inch. However, while running repeatability tests, it was found that minor variations in any of the parameters, including aluminum evaporated-film thickness, caused unsatisfactory results, and under-liquid jet etching was therefore deemed not acceptable for mechanization.

The next method tested was ultrasonic etching, in which ultrasonic energy was applied to the heated etch solution to break up or dislodge bubbles and promote uniform aluminum removal. Various combinations of ultrasonic energy, time, and temperature did not yield reproducible or satisfactory results and the method was abandoned.

Tests were also run using 7.5-percent to 15-percent solutions of potassium hydroxide instead of sodium hydroxide. No improvement in speed or quality of etching was observed.

The conclusion reached was that sodium hydroxide spray-etching of aluminum in air offers the best method for use in an improved automatic machine, and further tests will be run to determine optimum conditions.

3.5 Switching-Time Measuring Equipment

Various types of switching-time measuring equipment were investigated to find a suitable test set for final testing of semiconductor network devices. No conclusions have been reached yet, but it is expected that an order will be placed during the next quarter. A summary of several types follows.

3.5.1 Tektronix Type 567

This model will not be available until April or May, when production models will be introduced. Even with 3-month delivery, we could expect a test set no sooner than July or August.

The advantages of this system are low cost ($5, 000) and a recognized manufacturer. It has built-in, go, no-go testing.

Its disadvantages are long delivery time, the fact that it is not a proven system, and its low input impedance (50 ohms). Also, it has only one readout, and the conditions for each given time needed for a pulse measurement (t_d, t_r, t_s, t_f) must be set manually. The literature states that it can be programmed externally; however, the programming would have to be done at Texas Instruments.

3.5.2 Hewlett-Packard (Dymec-5844)

This system is more readily available and has been proven-in. It has the necessary high input impedance (100 kilohms) to the sampling oscilloscope. It has four digital, simultaneous readouts, desirable for production testing. It is more expensive ($15, 000) than other systems, but has accessories available for go, no-go testing and printer readout. This system appears to be the one best suited to our needs. Delivery time is 12 weeks.

3.5.3 Lumatron

Texas Instruments has several of Lumatron's instruments, and after conversations with various people who use them, the conclusion is that this machine presents some maintenance and servicing problems. It has meter readout and a low input impedance (50 ohms). The price is around $8, 000.

3.5.4 Texas Instruments — Houston

At present, Texas Instruments — Houston is working on a go, no-go system for another customer. This system has no visual readout or sampling oscilloscope, but one can be added. The test circuits use semiconductor networks, and there is considerable interest in the possibilities of this switching-time instrument. The price is $10, 000 to $15, 000.

3.6 Multiple-Point Bar Test Fixture

A study is under way to determine feasibility of various probe constructions to test individual scribed network bars. Contact will be made to all points that will be subsequently bonded so that operational or functional tests may be performed on a complete network device before mounting. Practical objectives include simple probe maintenance and replacement, and rapid alignment to the bars.

3.7 Test Jigs for Final Test

A local vendor was contacted to supply a test jig to replace the "finger boards" presently used in production. The objective was to get an idea of what could be done as far as size, shape, type of contacts, etc., are concerned. The vendor's design was unsatisfactory for several reasons. Other vendors will be contacted.

3.8 Electrical Testing

An evaluation of the methods used in assembly and final electrical testing has been started. A long-range program will be set up so that additional equipment can be added to handle high-level production. With long-range goals, equipment can be designed to be compatible with requirements for standard and special device testing at all production and Quality Assurance electrical test stations.

Types of testing under consideration are:

> Go, no-go acceptance or rejection to predetermined test limits, versus deigital readout of actual measured values.
>
> Station-by-station testing, where units are carried past a series of single-parameter test stations, versus one-station testing where each unit is inserted into a test station and rapidly subjected to all tests in sequence.
>
> Data recording systems using IBM cards, printed sheets, or punched tape.

3.9 Network Packaging

Effort during this quarter was directed toward improving the manufacturing capabilities of the welded network package described in the previous Interim Report. No significant changes in the design were made.

3.9.1 Package Material Investigations

3.9.1.1 Glass Preforms

Multiforms of Kovex 50 glass, made by Mansol Ceramic Company, were compared with the standard 7052 glass preforms usually used in assembly of packages. The Kovex 50 glass showed better flow characteristics under the same firing conditions and produced better parts. Further tests are being run to determine whether a change to Kovex 50 glass for production use is advisable.

3.9.1.2 Ring Frames

Castellated ring frames are produced by Precision Products Incorporated, Tulsa, by a process that involves blanking, drawing, and coining the Kovar pieces to shape. The problems of excessive wear of the coining die was solved by annealing the parts twice during the forming operation. The top surface of the ring must be flat and parallel for proper welding of the lid, but this condition has not been achieved with parts to date. The problem was solved by making the parts oversize and lapping the top surface to proper dimensions after coining. Another defect showed up as a metal overlap in the coined projections. Tests showed that this was not a leak path and the dies have been modified to correct this fault.

Deburring of rings was attempted by the vendor but produced too much rounding of the edges. A local vendor tried ultrasonic deburring with erratic results. The chemical roughening operation performed before oxidation was found to etch the burrs away and was adopted as the standard procedure.

3.9.1.3 Ceramic Bases

Ceramic bases as used inside the package are being investigated to determine if they can be purchased as fired instead of being ground to thickness. A 4-to-1 cost saving would result if the grinding operation could be eliminated.

3.9.1.4 Coined Lids

A Kovar bottom plate is welded to the castellated ring frame before package assembly to strengthen the structure. It was found that this lid should have a coined projection around its periphery to permit single-shot welding. The top lid for final package closure was also determined to require a projection for single-shot welding. A multistage blanking and coining die was designed and constructed after several unsuccessful attempts and produced very satisfactory coined parts.

3.9.1.5 Sylvania No. 4 Parts

Metal parts of Sylvania No. 4 metal to be sealed with G-12 glass were investigated as a substitute for Kovar. The chromium content in the alloy offers the possibility of producing a chromium oxide surface with improved metal-to-glass sealing properties. The plating shop experimented with various oxide-removal methods to permit gold plating after firing, but was unsuccessful in removing the chromium oxide without damaging the thin leads. Contact has been established with the vendor, Carpenter Steel Company, for further assistance.

3.9.2 Package Assembly

3.9.2.1 Firing Boats

The new B. T. U. Engineering Company firing furnace was received and installed. Prove-in is under way on this machine at present.

New graphite firing boats have been designed and ordered from Speer Carbon Company. The boats are constructed to hold 22 assemblies each. They will reduce loading time and will increase furnace capacity by six times.

3.9.2.2 Bottom Plate

The coined bottom plate was successfully welded to the bottom of the castellated ring frame with the Taylor-Winfield field welder. A welding electrode with a gimbal action for self-alignment was installed on the welder for this purpose. Placement of the lid is currently manual, but designs are under way for an automatic welding jig.

3.9.3 Package Closure

3.9.3.1 Resistance Welding

Tests were continued to determine the possibility of welding a lid to the top of a completed package in a single operation. Lids with a sharp coined projection offered the most promising part to use because a solid projection is required to concentrate the weld energy in a thin line around the rim of the package. First attempts showed nonuniform welding, with some areas underwelded and other areas overwelded as revealed by overheating and burning of the side walls.

Packages were next lapped carefully before plating to produce a flat, parallel upper face. The gimbaled self-aligning electrodes were used, and lids were checked to make sure they represented the best part that could be produced by coining. These precautions gave better and more uniform welds, but it was still not possible to increase the welding current enough to produce a properly welded joint without overheating and damaging the side walls. Assistance was sought from Raytheon, Taylor-Winfield, and Sylvania welding experts, and all confirmed that single-shot resistance welding of this package was not feasible.

The package design is fixed at present by the allowable height, width, and length, and by the internal dimensions required to mount the silicon bar elements. Within these limitations, it does not seem possible to design an external welding flange or to change the wall dimensions to permit conventional, single-shot welding. The alternate principle of dividing the weld energy into increments is a sound one, however, and leads to stitch-on or seam-welding approaches that look very promising.

3.9.3.2 Stitch Welding

Packages have been sealed successfully by spot-welding a series of overlapping welds around the edge of the lid. A Weldmatic capacitor-discharge spot-welder was used with a large copper bottom electrode and a 0.010-inch tip on the top electrode. Welds were made 0.010 inch apart by manually moving the package underneath the weld electrode. Approximately 75 welds are required to complete the weld seam. This operation can be mechanized for production when required.

3.9.3.3 Brazing

Brazing of lids was investigated as a closure method. Lids were gold-plated, then evaporation-coated with germanium to produce a gold-germanium solder coating. The brazing fixture consisted of a heated anvil on a lowering mechanism having provision for adjusting pressure, dwell time, and forming-gas atmosphere. Several packages were sealed without leaks and without apparent effect on the devices inside. The temperature reached was above 400° C, however, and would damage gold-bonded connections unless means were found to keep the silicon bar cooler. Further tests will be run on braze-closure of packages.

SECTION IV

PILOT-LINE EQUIPMENT

Equipment is being designed, constructed, and evaluated for use on the pilot production line to obtain efficient, high-production-level operation at an unbalanced rate of 100 good units minimum per day. Following is the status of each item of equipment.

4.1 Etch-Polish Machine

The etch-polish machine produces a highly polished, damage-free surface on lapped silicon slices for subsequent processing through the diffusion operations. It operates by chemically etching slices on both sides in an oscillating slice basket followed by rapid water quenching. A production machine was designed to be safer and of higher capacity to replace the prototype mechanism now in use. This new design has been changed to make all operations fully automatic through etching, quenching, and water-washing steps. The machine will be incorporated in a stainless-steel hood for uniform appearance. Design is completed and has been released for fabrication.

4.2 Prediffusion Cleaning Machine

Prediffusion cleaning of slices is performed to remove all exposed photoresist film and other impurities before the next diffusion. Tests have shown that hot sulfuric acid removes the hardened resist film without affecting the oxide or diffused impurity layers. An in-line transport cleaning machine is now being designed to carry slices through hot sulfuric acid, cooling, water-quenching, hot nitric acid, and water-washing operations. A second machine for pre-evaporation cleaning will be built with modifications to eliminate the nitric acid etch.

Final hot deionized water washing will be included in each cleaning machine so that slices are ready for loading into diffusion boats when finished. The machines will be mounted in stainless steel fume hoods with special exhausting for the acid fumes.

Design completion is scheduled for April 1962, with construction to be finished in early June.

4.3 Three-Slice Photoresist Spinner

A second, high-production photoresist spinner for the application of photoresist is being designed to supplement the existing triple spinner unit. Modifications are required to permit mounting the two spinners to the right and left of the central conveyor belt of the baking oven. In this manner, a single operator can alternate loading and unloading one machine while the other machine completes its automatic cycle. Design has been completed, and delivery is due in early May 1962.

4.4 Mask-Alignment Fixtures and Lighthouse

The mask-alignment fixture aligns glass photographic masks to KMER-coated slices to achieve exact registration with previously applied oxide patterns. After registration, the fixture is placed under a light source for rapid exposure of the photoresist film. This is a change from previous designs in which two fixtures were required per station on a turnaround mounting for long exposure during alignment. Six fixtures will be located along the slice conveyor system, and a seventh fixture will be set up in another location for rework and experimental use.

The production fixture is being designed to incorporate the best principles of prealignment, locate-and-rotate motions, Unitron mechanical stage, vertical adjustment for alignment and clamping of glass-masks to slices, and quick-change masks. The new lighthouse contains a mercury-arc reflector spotlamp equipped with a shutter and directed downward to the rear of the alignment microscope and fixture. After alignment, the holding fixture is slid back under the lamp for rapid exposure. Design will be completed in April, and construction of seven units is scheduled for completion early in June.

4.5 Dual-Beam Optical System

This accessory brings together in the field of a single microscope the magnified images of two alignment marks spaced 0.490 inch apart for rapid alignment in a single operation of all points on the slice and mask. The prototype instrument was completed and worked as planned, but contrast was poor because of numerous reflections in the optical system. Performance was considerably better after a nonreflecting coating was applied to all optical surfaces. Further improvement in image quality was obtained by changing the microscope objective lens from 16.3X to 10X. The system is now very satisfactory, and seven additional attachments are on order from the Apparatus Division for June delivery.

4.6 Photoresist Developing Machine

This machine develops exposed photoresist patterns by removing unexposed areas. It is a rotary, dial-type machine that moves slices past oscillating spray heads for the various solutions. Prove-in of the machine showed that the basic operation was very satisfactory. Modified slice holders were found necessary to prevent loss of slices because of the force of the sprays. The machine was further modified by adding a new enclosure to house all controls and to provide an attractive, uniform appearance with other new machines. The developing machine is now completed and ready for use.

4.7 Oxide Etch Machine

This is a rotary machine that automatically lowers slice fixtures into oxide-removal etch and water baths to remove oxide layers not protected by photoresist (Figure 1). The rotary head moves 120° per cycle to carry two fixtures at a time into the three positions of load and unload, etch, and water rinse. The overflow water circulates around the etch tank to keep it at a constant temperature and to catch etch drippings. Fabrication and installation have been completed, and the machine is working satisfactorily.

4.8 Evaporation Fixtures

Fixtures for evaporation of aluminum onto slices have been redesigned to allow upward evaporation onto 19 slices from a number of filaments. Figure 2 shows the new design. More than one filament is required to eliminate shadowing and open leads because of the step structure in the underlying oxide layers. A sealed heating element coiled into hemispherical shape is clamped to the top or back side of the slice holder to heat the slices during evaporation. Fixtures are completed and in use and are adequate for present needs but will require modification for increased capacity after evaluation and operation.

4.9 Bar Scriber

The production bar-scribing machine is performing satisfactorily in the scribing of silicon slices into individual bar elements. A new, truncated, four-sided diamond point has proved effective and has been adopted for production use. An angle 20° from the vertical was found best for the diamond scribe arm adjustment.

4.10 Component Probe-Test Fixtures

Two additional component test fixtures for probe-testing slices were completed. These fixtures permit as many as three adjustable probe points to be located on any desired component on a bar for curve-tracer electrical measurement. Slices may be lowered and raised under the points, and a grease-plate manipulator permits X-Y slice location.

Modifications will be required for easier loading and unloading of slices and to improve the probe pivot action.

4.11 Multiple-Point Probe-Test Fixture

A prototype design has been completed for a fixture to probe-test individual bars by making contact simultaneously to all points on the evaporated-lead pattern required for an operational test. Individually sprung wire probes are located in holes in an insulated plate which is lowered and aligned to the bar. Fixtures should be completed in April 1962.

A manipulator and bar-holding fixture is being constructed to facilitate evaluation of the multiple-point principle for production testing.

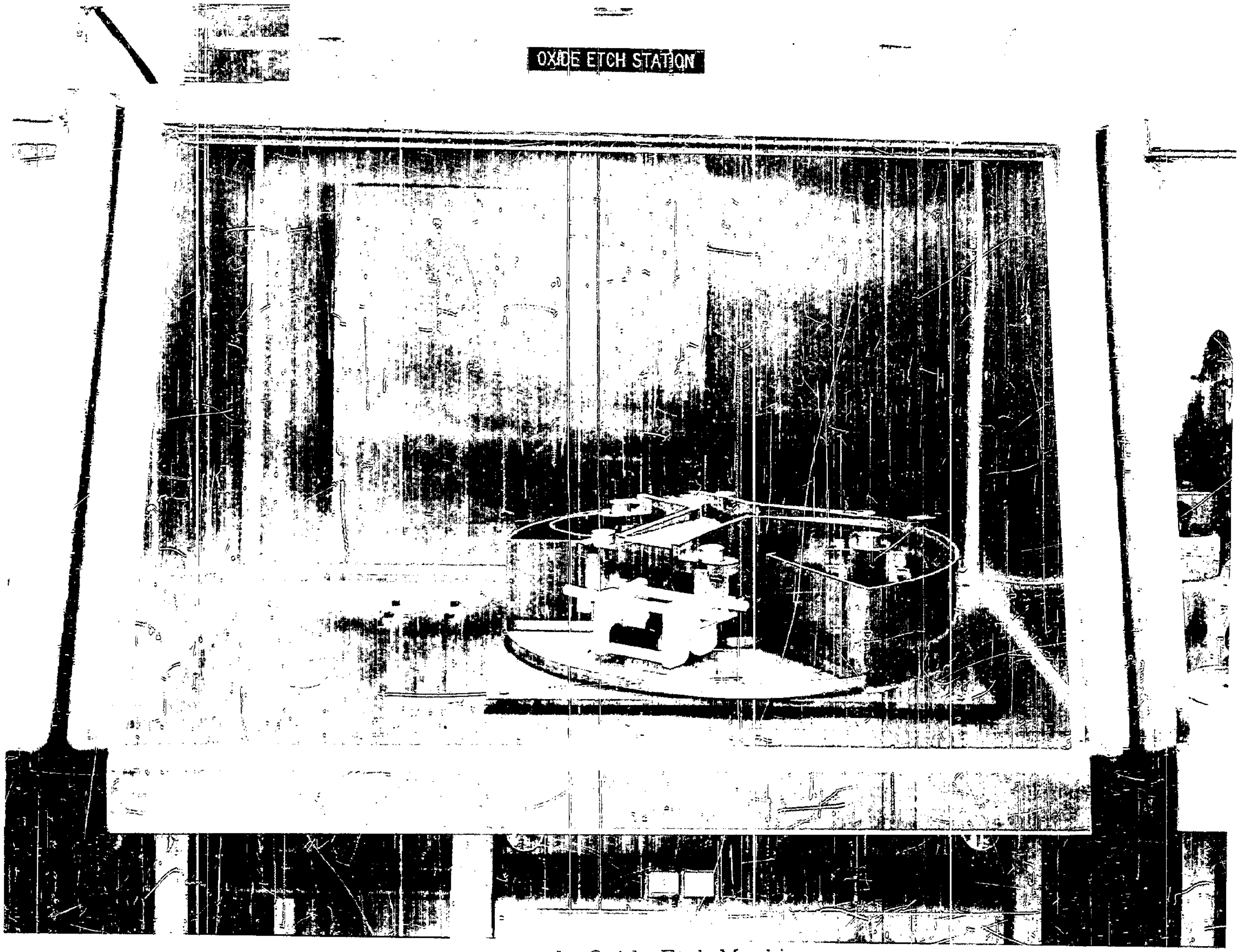

Figure 1. Oxide Etch Machine

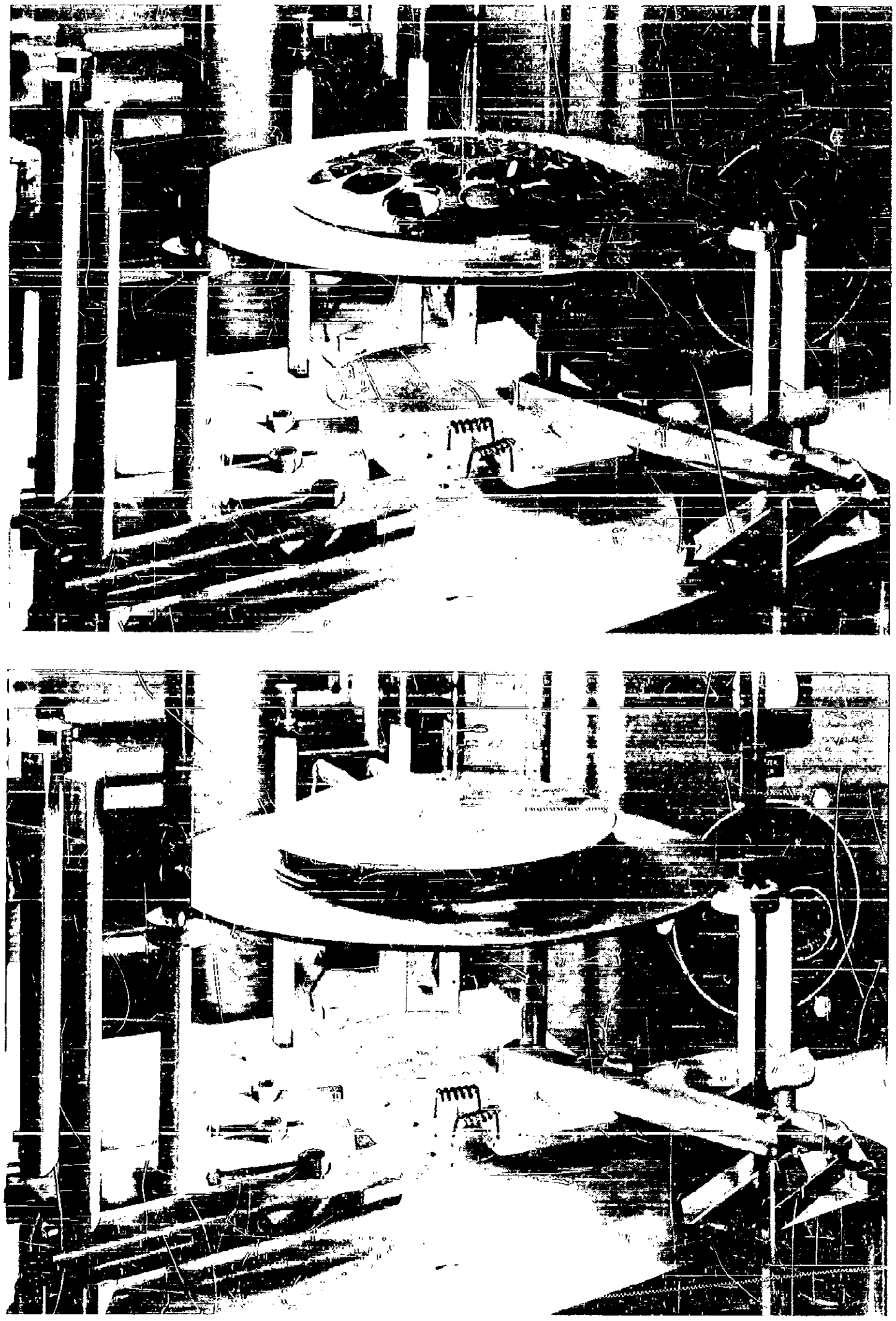

Figure 2. Evaporation Fixtures

4.12 Vacuum Alloying Station

A prototype fixture has been constructed to alloy evaporated aluminum areas in the vacuum of an evaporator bell jar. Thirty slices at a time are heated by an array of eight 500-watt quartz infrared heating elements. Tests are being run to determine the effectiveness of this method, which is adaptable to evaporating and alloying in the same fixture with one pumpdown.

4.13 Diffusion Furnaces

Twelve diffusion furnaces are under construction to provide improved facilities with adequate capacity for production diffusion of top-contact planar network logic devices. The furnaces are mounted in two consoles with six per console, stacked three high. Each furnace has three controlled temperature zones, which are adjustable to give a flat operating region within ±0.5° C over a minimum length of 15 inches. For easy access and operation, controls for temperature, zone balancing, source furnace temperature, programed cooling rate, and operating gas flow are all mounted on the console exterior panels opposite each furnace.

The furnaces are scheduled for completion in late May for prove-in during June 1962.

4.14 Final Electrical Test Equipment

Three automatic final electrical test sets are being designed and built for final testing of network units. These sets will step through all required dc measurements automatically using a digital voltmeter readout. They also will have the ability to drive an IBM 526 summary punch if recorded data is needed. Semiconductor network flip-flop and logic gate units will be used in the test-set circuits, and their readouts will be displayed on the front panel.

All parts have been received except relays and printed circuit boards. Each set will have a capacity of 45 units per minute. Construction is scheduled for completion in May 1962.

It is now generally felt that final testing of network devices should employ go, no-go presentation and selection. This test method will facilitate high-level final testing operations and will be incorporated into future designs.

4.15 Test Jigs for Final Test

Two more vendors have been contacted and design work is progressing to supply a test jig that will offer quick loading and unloading and a more positive contact to the network leads for final testing of completed networks. The most promising design involves a series of formed springs to transfer contact from the network leads to a printed circuit board adapter. It will be constructed as a prototype unit for evaluation.

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APPENDIX

SHEET RESISTANCE OF DOUBLE DIFFUSED STRUCTURES

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SHEET RESISTANCE OF DOUBLE-DIFFUSED STRUCTURES

Graphs allowing diffused layer surface concentration to be determined from the reciprocal sheet resistance-junction depth product and the uniform bulk doping level for various distributions of diffused impurity have been published by Backenstoss[1] and corrected by Irvin[2]. These curves can also be used to determine the diffused layer surface concentration and junction depth needed to achieve a given sheet resistance for a single diffused layer.

To achieve electrical isolation of the several elements of a semiconductor network, a triple (or sometimes quadruple) diffused structure is employed. While the first diffusion can be characterized by the Backenstoss-Irvin curves for a gaussian distribution, the second diffusion departs from the conditions assumed by Backenstoss in that the junction is formed by compensation of a previously diffused layer rather than a uniformly doped substrate. A first order correction term that allows Irvin's curves to be used for a second diffusion is calculated here.

The reciprocal sheet resistance, $\frac{1}{\rho_s}$, of a diffused layer is given by

$$\frac{1}{\rho_s} = \int_{X=0}^{X=x_j} \sigma(X)\, dx \qquad (1)$$

where x_j is the junction depth, and $\sigma(x)$ is the conductivity at depth x in the diffused layer. Experimental conductivity data[2] in the range of interest can be expressed by a series of the form

$$\sigma = a + bN^{1/2} + CN\,. \qquad (2)$$

The net number of impurities in a single diffused layer with a gaussian distribution is given by

$$N_x = N_s \exp^{-\alpha x^2} - N_o \qquad (3)$$

---

[1] Backenstoss, G., B.S.T.J., 37, 1958, p. 699

[2] Irvin, J.C., B.S.T.J., 41, 1962, p. 387

Where N_s is the surface concentration, N_o is the uniform bulk doping, and α is given by

$$\alpha = \frac{1}{4Dt} \, . \tag{4}$$

Using the first two terms of a binominal expansion to express $N_x^{1/2}$ gives

$$N_x^{1/2} = N_s^{1/2} \exp \frac{-\alpha x^2}{2} - 1/2 \frac{N_o}{N_s^{1/2}} \exp \frac{\alpha X}{2} \, . \tag{5}$$

The conductivity as a function of x is then

$$\sigma(x) = a + bN_s^{1/2} \exp \frac{-\alpha X^2}{2} - \frac{b}{2} \frac{N_o}{N_s^{1/2}} \exp \frac{\alpha X^2}{2} + CN_s \exp^{-\alpha X^2} - C N_o \tag{6}$$

The integral in Eq. (1) is then

$$\frac{1}{\rho_s'} = \int_0^{X_j} \left\{ a + b N_s^{1/2} \exp \frac{-\alpha X^2}{2} - \frac{b}{2} \frac{N_o}{N_s^{1/2}} \exp \frac{\alpha X^2}{2} + cN_s \exp^{-\alpha x^2} - cN_o \right\} dx \, . \tag{7}$$

The sheet resistances given by Eq. (7) are equal to those already tabulated by Irvin and will be indicated by a prime.

For a diffusion indentified by subscript 2 on top of a diffusion identified by subscript 1, the net concentration assuming gaussian distributions and ignoring the contribution by the uniform bulk doping is

$$N_x = N_{s2} \exp^{-\alpha_2 x^2} - N_{s1} \exp^{-\alpha_1 x^2} \tag{8}$$

Going through the same steps as above we see that

$$\frac{1}{\rho_s''} = \int_0^{X_2} \left\{ a + bN_{s2}^{1/2} \exp \frac{-\alpha_2 X^2}{2} - \frac{b}{2} \frac{N_{s1}}{N_{s2}^{1/2}} \exp \frac{-\alpha_1 X^2}{2} + \frac{\alpha_2 X^2}{2} + cN_{s2} \exp^{-\alpha_2 X^2} - cN_{s1} \exp^{-\alpha_1 X^2} \right\} dx \, . \tag{9}$$

For typical double diffused structures

$$\alpha_2 \gg \alpha_1 \tag{10}$$

and Eq. (9) can be approximated by

$$\frac{1}{\rho_{s''}} = \int_0^{X_2} \Big\{ a + bN_{s2}^{1/2} \exp \frac{-\alpha_2 X^2}{2} - \frac{b}{2} \frac{N_{s1}}{N_{s2}}^{1/2} \exp \frac{\alpha_2 X^2}{2} + cN_{s2} \exp^{-\alpha_2 X^2} - cN_{s1} \exp^{-\alpha_1 X^2} \Big\} dx \tag{11}$$

Comparison of Equations (7) and (11) shows that

$$\frac{1}{\rho_{s''}} = \frac{1}{\rho_{s'}} + \int_0^{X_2} cN_{s1} \, dx - cN_{s1} \int_0 \exp^{-\alpha_1 X^2} dx \tag{12}$$

where $X_1 \rightarrow X_2$ $N_s \rightarrow N_{s2}$ and $N_o \rightarrow N_{s1}$ in Equation (7).

Then

$$\frac{1}{\rho_{s''} X_2} = \frac{1}{\rho_{s'} X_2} + \frac{cN_{s1}}{X_2} \left(X_2 - \frac{\sqrt{\pi}}{2} \frac{1}{\sqrt{\alpha_1}} \operatorname{erf}(\sqrt{\alpha_1} X_2) \right) \tag{13}$$

where the first term can be found from Irvin's tabulation and the correction term can be simplified to

$$cN_{s_1} \left(1 - \frac{\sqrt{\pi}}{2X_2} \frac{X_1}{\ln \frac{N_{s1}}{2N_o}} \operatorname{erf} \left(\ln \left(\frac{N_{s1}}{2N_o} \right) \frac{X_2}{X_1} \right) \right. \tag{14}$$

since in Equation(3), $X = X_1$ for $N_x = 0$, and

$$\alpha_1 = \frac{\ln \frac{N_{s1}}{N_o}}{X_1^2} \qquad (15)$$

A typical double-diffused structure is a p-type base diffused into an n-type diffused collector. The parameters in this case might be

$N_{s2} = 1.0 \times 10^{18}$

$N_{s1} = 1.0 \times 10^{17}$

$N_o = 1.0 \times 10^{15}$

$\frac{X_1}{X_2} = 4$

For $10^{19} > N > 10^{17}$ the conductivity of p-type silicon can be expressed by

$$\sigma = 0.02 + 9.56 \times 10^{-9} N^{1/2} + 6.32 \times 10^{-18} N \qquad (16)$$

For this example,

$$\frac{1}{\rho_x X_2} = 8.4$$

and the calculated correction term is 0.16 giving $\frac{1}{\rho_s X_2} = 8.56$

The correction for this example is less than 2%. Considering the errors in measuring ρ_s and x_j one would be justified in this case in using Irvin's data with $N_{s2} \rightarrow N_s$, $N_{s1} \rightarrow N_o$, and $X_2 \rightarrow x_j$.

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Unclassified Report

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