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LASER-ZONE GROWTH IN A RIBBON-TO-RIBBON (RTR) PROCESS
SILICON SHEET GROWTH DEVELOPMENT FOR THE LARGE AREA
SILICON SHEET TASK OF THE LOW COST SILICON SOLAR
ARRAY PROJECT

Motorola Report No. 2256/6

Technical Quarterly Report No. 5

June 1977

JPL CONTRACT NO. 954376

BY
R.W. Gurtler, A. Baghdadi, J. Wise, R.J. Ellis

PREPARED BY
MOTOROLA INC. SEMICONDUCTOR GROUP
5005 East McDowell Road
Phoenix, Arizona 85008

"This work was performed for the Jet Propulsion Laboratory,
California Institute of Technology, under NASA Contract
NAS7-100 for the U.S. Energy Research and Development
Administration, Division of Solar Energy."

"The JPL Low-Cost Silicon Solar Array Project is funded
by ERDA and forms part of the ERDA Photovoltaic Conversion
Program to initiate a major effort toward the development
of low-cost solar arrays."

(NASA-CR-153908) LASER-ZONE GROWTH IN A
RIBBON-TO-RIBBON (RTR) PROCESS SILICON SHEET
GROWTH DEVELOPMENT FOR THE LARGE AREA
SILICON SHEET TASK OF THE LOW COST SILICON
SOLAR ARRAY PROJECT Quarterly (Motorola, G3/44 39181

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<td>36</td>
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</tr>
</tbody>
</table>
1.0 RTR Growth Apparatus

1.1 Contract Goal Implications

The primary crystal growth goals for the ERDA JPL contract extension are as follows:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Target</th>
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<tbody>
<tr>
<td>Width</td>
<td>7.5 cm</td>
</tr>
<tr>
<td>Growth Rate</td>
<td>18 cm/min</td>
</tr>
<tr>
<td>Thickness</td>
<td>.01-.025 cm</td>
</tr>
<tr>
<td>Efficiency</td>
<td>&gt;12%</td>
</tr>
<tr>
<td>Dislocation Density</td>
<td>&lt;10^4 cm^-2</td>
</tr>
<tr>
<td>Length</td>
<td>&gt;10 m</td>
</tr>
</tbody>
</table>

The primary requirements which most affect the RTR apparatus are the width velocity and the changeover from a finite stroke machine to a continuous growth capability. The increased width and velocity require an improved scanner and higher laser power as has been reported previously. Briefly, the highly focussed laser beam must approximate a line source of energy and if the scan frequency is not high enough, vaporization and roughening of the surface will result. In addition, the reflectivity of the liquid silicon has been shown to be much higher than expected and at present, our growth velocities are limited to about 7.5 cm/min for 1.25 cm wide and .1 mm thick ribbons. This was accomplished with a laser power of 350 watts (10.6 μm).

Scaling these numbers to 7.5 cm wide, 7.5 cm/min would indicate 2 kW would be required from the laser. However, as reported in the March 1977 Quarterly Report, utilization of hemispherical reflectors can improve the energy coupling by at least a factor of two, and use of Nd:YAG lasers at a wavelength of 1.06 μm also indicates a substantial coupling improvement.

To achieve the width and velocity goals, and to evaluate the performance of Nd:YAG vs. CO₂ lasers, a trial lease of both lasers was decided upon. After about three months of evaluation of both lasers under similar operation, a decision to purchase one of the lasers will be made. For these evaluations, two Quantronix Nd:YAG lasers, each rated at 375 W for a total of 750 W, and
a Sylvania CO$_2$ laser rated at 1.5KW were contracted. These two laser systems and the existing 375W Photon Sources CO$_2$ laser will comprise the system of laser sources for the evaluation period.

1.2 New RTR Facility

Coinciding with the construction of the new equipment is a departmental move from one plant to another. Consequently, a totally new crystal growth laboratory has been designed. Two distinct experimental growth stations will be provided as indicated in Figure 1. Two independent growth stations are provided which can allow growth experiments to be run at one station while experimental modifications are being made at the other. The laser beams are brought to either station by means of a beam table: the beam table is totally enclosed from the point of exit from the laser, to the entrance of each station. Mirrors and lenses within the enclosed beam table are in an inert, filtered atmosphere which will ensure long life for the high power mirrors and lenses. Plumbing and electrical wiring to each station are confined beneath a false floor so as to minimize obstacles around the stations. Each station is equipped with a cover which serves as a personnel protection cover, allowing observation of the experiment through laser-opaque windows.

The tables themselves utilize optical table concepts with provision for magnetic base mounting or hard mounting to an array of 1/4-20 tapped holes in the plate. This will allow a great versatility in design changes or optical layout modifications.

One station will utilize the existing, finite stroke RTR apparatus for experimentation which does not require the special scanning and feed requirements of the new apparatus.
FIGURE 1: LASER LAB

LASER-OPAQUE WINDOWS
PERSONNEL PROTECTION COVER
375W CO₂ LASER
Nd:YAG LASERS (2)
1.5kw CO₂ LASER
BEAM TABLE (PURGED)
BEAM TABLE COVER
OPTICAL BENCH
OPTICAL COMPONENTS
EXPERIMENTAL CHAMBER
BEAM SWITCHING CHAMBER
FALSE FLOOR FOR ELECTRICAL CABLELING, PLUMBING
Figure 2 illustrates in more detail how the beam table and experimental tables are configured to allow versatile experimental conditions. Each laser beam can be directed to either table.

At the entrance to each table is an interlocked system of shutters which will not allow the high power laser beams access to the tables unless the cover is in place; low power HeNe alignment laser beams can be allowed to the table for set-up however. Each beam passes through a window at the end of each arm of the beam table; this allows the atmosphere in the beam table to be undisturbed during work on one of the tables.

As indicated in Figure 3, the two Nd:YAG lasers are being used for one experiment on Table 1 while the high power CO₂ laser is being used on Table 2. Note, that different lenses and mirrors are often required for the two distinct wavelengths and this requires that all mounts be capable of quick changeover.

1.3 New Experimental Table

Figure 2 indicates the general layout of optical components for the new RTR apparatus. Beam directing mirrors and (in the case of the CO₂ laser beams) beam splitters are used to bring two nominally equal beams to the polygon scanners. The scanner assemblies then allow remote adjustment of focus, scan width, and scan position on the sample in the experimental region. Figures 3 and 4 indicate the concept for the table, component mounting and table cover. Basically, to allow for experimental variation, all components related to the upper portion of the uptake transport, transport drive etc. are mounted to a common plate which may be raised or lowered en masse by means of a single column and a couple of adjustable, relocatable support columns around the periphery. All components related to the lower transport, transport drive and ribbon orientation are mounted on the base plate.
COOLED WINDOW PLATE
2 Required (ONE SHOWN)

BEAM SPLITTER

BEAM DIRECTING MIRROR (ROTATABLE)
4 Required

BEAM DIRECTING MIRROR
(MAGNETIC)
15 Required

POLYGON SCANNER

EXPERIMENT REGION

POLYGON SCANNER

EXPERIMENT REGION

SHUTTER MIRROR
(ONE SHOWN)
8 Required

SCANNING MIRROR

WATER COOLED ABSORBERS
2 Required

COVERED BEAM TABLE
(PURGED)

BEAM DIRECTING MIRROR
(FIXED)

HI-Power 1.5KW

YAG #1

YAG #2

375KW
PERSONNEL PROTECTION COVER (REMOVABLE)

WORK TABLE (PURGED)

FIGURE 3: CRYSTAL GROWTH TABLE AND COVER
The cover also mounts on the single massive column and may be lowered over the entire apparatus and locked to the base plate, thus making a seal with the table periphery.

Ribbon transport is accomplished by a roller mechanism and will initially be mechanically guided along the edges.

Guiding of the ribbon in the thickness direction will also be accomplished mechanically initially but gas dynamic bearings will be tested and developed. Ribbon transport velocities will be stepper motor controlled and are designed to have a maximum velocity of 25cm/min.

1.4 Operation of New Facility

The move to the new facility is now scheduled in late July and operation is hoped for in mid August. However, the existing facility will be maintained operational as long as possible.

2.0 Crystal Growth and Crystallographic Characterization

Crystal growth during this quarter involved "routine" growth runs, and experimental growth runs attempting to utilize a curved melt configuration to enhance crystallinity.

2.1 Routine Growth Runs

A large number of (30) samples were grown, from single crystal feedstock, in the 2:1 differential mode at a growth rate of 2" minute. The feedstock was 8 mils thick, the re-grown ribbon is 4.5 mils thick. The constant gradient furnace was used to reduce stresses in the ribbon samples during growth. The ribbon edges did not grow in a straight line (see Figure 5). The "serrated" edges were a result of an instability at the edges of the molten zone, which has only been observed when growing in the differential mode.

Figure 5 is a schematic of sample 369, which is typical of the whole run of samples. The sample was etched for 5 minutes in Wright etch in order
FIGURE 5. SAMPLE 351, West Edge
FIGURE 6. Sample 369

PHOTO SCALE

100µm

160,000/cm²

17,000/cm²

3,200 linear defects/cm

800,000/cm²

50,000/cm²

1,200 linear defects/cm

1,900 linear defects per cm²

190,000 dislocations per cm²

ORIGINAL PAGE IS OF POOR QUALITY
to delineate the twin planes, grain boundaries and dislocations. The
dislocation density ranged from 50,000 dislocations/cm² to $1.2 \times 10^6$
dislocations/cm². The linear defect density ranged from 1,000 to 3,000
linear defects/cm. Thus, although the linear gradient furnace effectively
reduced the macroscopic stress in the silicon ribbon, it has apparently had no
significant effect on the ribbon defect density. The dominant grains at
the end of the crystal growth had -(110) and -(115) orientations (See Figure
6).

A number of samples from these runs have been processed into solar cells
and some characterization of cells has been completed on a few cells; this is
reported below under material/device measurements. (Section 2).

2.2 Curved Melt Growth

In order to attempt to achieve larger crystalline sizes, attempts were
made to achieve a curved melt configuration. A simple method for achieving
the required curved melt configuration. A simple method for achieving
the required curved melt was conceived which did not require the complex,
dual scanning (x-y), technique utilized in earlier experiments.

The method used to achieve the curved melt is depicted in Figure 7.
A flat tungsten foil (=.01" thick) was mounted in an optical mount, which
happened to be available, which could compress the foil lengthwise in order
to achieve a desired amount of buckling. The bent foil was mounted just
prior to the ribbon and reflected the scanning laser beam at a grazing angle
with some slight vertical deflection. The amount of curvature could be
varied by buckling the beam greater or lesser amounts.

2.2.1 Growth Experiments

Numerous growth runs were made but even though the technique would appear
simple, numerous problems prevented us from achieving any samples worthy
of further characterization.
Figure 7: Method Utilized to Achieve a Curved Melt Zone for RTR Growth
Sample grown from single crystal feedstock using a curved molten zone.
FIGURE 9: Sample grown from Polycrystalline feedstock using a curved molten zone.
One problem resulted from the particular curvature required for crystal size enhancement. As indicated in Figure 7, the beam must be deflected and curved in such a manner that the beam which continues past the silicon is now directed into the furnace. Space limitations prevent the reflector from being above the melt and deflecting away from the furnace. This beam which hits the furnace caused vaporization of a quartz muffle and insulation which would invariably get into the melt region giving very poor looking ribbons.

In order to attempt to prevent the beam from entering the furnace, platinum shields were fashioned around the entrance slot. However this was not altogether successful either as the beams were still able to enter the furnace through multiple reflections from the furnace. A proper shield will require rather critical sizing in order that the ribbon may pass through the slot without touching the ribbon but yet prevent the upward deflected beam from entering the furnace. As a means to temporarily solve the problem the melt was allowed to occur further from the furnace entrance but this has resulted, so far, in increased stress and large edge and surface distortions.

2.2.2 Results

Some curved melt growth runs were moderately successful. Examples of samples grown at 1"/min. from polycrystalline feedstock (sample 417) and single crystal (110) [100] feedstock (sample 423) are shown in Figure 8 and 9, respectively. The orientation of the large grain produced in sample 417 is (213) [253], and the large grain in sample 423 is (113) [50]. This latter orientation has occurred frequently in earlier samples.

For comparison, a number of samples were grown at 1"/min. from polycrystalline feedstock using a flat molten zone. Figure 10 is a schematic of sample 464, which was typical of this series. Laue photographs taken at the points marked x in Figure 10 all showed roughly the (110) [112]
FIGURE 10  SAMPLE 464 - GROWTH FROM POLYCRYSTALLINE FEEDSTOCK USING A FLAT MOLTEN ZONE
orientation. Other dominant grains observed on samples grown from poly feed-
stock using a flat molten zone include -(211) [022]; -(552) [111]; -(123) [210].

In the majority of samples the large grains are actually composed of a
high density, very fine twin bundle structure. The samples shown in Figures
8, 9, and 10 were Wright etched to delineate their grain boundaries.

3.0 Material/Device Characterization

3.1 Solar Cells

Samples submitted to the solar cell processing area have offered some
difficulties during late photoresist steps, but a few ribbons have been
completed. Evaluation of these first solar cells, the first completed
since the addition of the linear profile furnace and attainment of higher
growth velocities (2"/min.), shows substantial improvement in performance
over previous cells. Even of the few ribbons completed, several of the
test cells exhibited metallization shorts due to photoresist problems.
The best control sample and the best ribbon of this first group have
been evaluated. Figure 11 shows a photo of the ribbon sample evaluated.
Figures 12 and 13 show load plots for the cells which have been normalized
to active area; excluded the large "bar" center contact.

As can be seen from Figure 12, the measured efficiency is just over 10%;
this represents the best cell so far on RTR. The control cell (Figure 13)
exhibited an efficiency of 12.4%. Figures 14 and 15 are spectral response
plots for these same cells; from these we see evidence not only of losses
in the long wavelength portion of the spectrum, as expected for the short
diffusion lengths measured on RTR ribbons, but also significant losses in the
short wavelength regime. This most likely points to a junction depth
problem. Since, as Figure 11 shows, multiple orientations occur in the cell,
variations in junction depth might occur due to the various orientation,
but may also occur along grain boundaries. Sectioning will be performed
on typical cells to attempt to indicate the short wavelength degradation.
SAMPLE #355
EFFECTIVE CELL AREA 1.1cm²

FIGURE 11: RIBBON SOLAR CELL
RIBBON SOLAR CELL

FIGURE 12: LOAD CURVE OF SOLAR CELL
CONTROL SOLAR CELL

FIGURE 13: LOAD CURVE OF CONTROL CELL

Sample #354
n = 12.48
P.F. = 64.58
SPECTRAL RESPONSE (RIBBON)

WAVELENGTH (μM)

RELATIVE RESPONSE (%)  100  80  60  40  20  0

AMPLITUDE

QUANTUM EFFICIENCY

SAMPLE #355
η = 10%

FIGURE 14: SPECTRAL RESPONSE (RIBBON)
SPECTRAL RESPONSE (CONTROL)

SAMPLE #354
\[ \eta = 12.4\% \]

WAVELENGTH (\(\mu\text{M}\))

RELATIVE RESPONSE (\%)

AMPLITUDE

QUANTUM EFFICIENCY

FIGURE 15: SPECTRAL RESPONSE (CONTROL)
SPV measurements have also been performed on the ribbon and control cell. These were performed using the open circuit voltage of the cell as the "surface" voltage. The diffusion length measured on the control cell was about 100µm. Figure 16 shows results of measurements on the ribbon cell at various points. A light spot of about 1.5mm in diameter was used. Note that the values given (28-38µm) are significantly higher than the 10-15µm values measured prior to processing. No real correlation with the presence of grain boundaries is noted but some orientation dependence might be evident.

Both the control and ribbon cell were measured under "one sun" conditions and dark conditions; virtually no effect was noted on measured diffusion lengths in contrast to reports by Tyco.

3.2 SPV Studies

The light level dependence of SPV measurements has been a concern to us for both measurements on standard crystals as well as for ribbon. Tyco has reported an increase in diffusion length with illumination level for short circuit current analysis of ribbon solar cells while little dependence was shown for Czochralski cells. The conventional SPV method for substrate evaluation utilizes considerably lower light levels than "one sun" for its measurement and brings into question its value for solar cell material evaluation. Choo and Sanderson* have analyzed the effects of traps on measured diffusion lengths by the SPV method. Their conclusion was that under most conditions of minority carrier trapping, the measured diffusion length will be longer than one without shallow traps. This has been observed in measurements on some single crystal samples. One example may be cited. A Wacker, p type 1.9Ωcm, crystal, float zone, was measured in the dark with a diffusion length and lifetime of 500µm and 125µsec respectively. Illumination of the back surface of the 15 mil thick sample

*S.C. Choo and A.C. Sanderson, Solid State Electronics, 13, pp. 609-617
OPEN CIRCUIT PHOTOVOLTAGE
DIFFUSION LENGTH MEASUREMENTS

FIGURE 16: SPV ON RIBBON CELL
at a light level of ~.01 suns yielded values of 160μm and 12.8μsec -- more typical of 1.9Ωcm material.

These effects need (and will receive) more study to ascertain what might be the proper conditions for measurement. In addition, some effort is also underway to obtain a low temperature Schottky barrier solar cell structure which will allow SPV-like measurements to be made at high ambient illumination without the problem of saturation of the photovoltage. In this regard, In-Sn-O transparent electrodes were sputtered onto a sample in an attempt to make Schottky solar cells. This was successful but good SPV measurements have not yet been made in this manner. Reflectivity corrections need to be made and this might be a source of some of the problem.

3.3 SPV Material Studies

While many authors have reported on the variation of lifetime due to dislocations, oxygen precipitation, point defects clustering, etc., it is still not clear which mechanism is primarily contributing to the lifetime degradation observed in RTR growth (maybe all of them).

Since RTR ribbons definitely exhibit large variations in dislocation densities and undergo rapid variations in temperature, some experiments were performed to simulate these conditions without actual crystal growth.

In addition these experiments were intended to evaluate the performance of our linear profile furnace for preventing and/or relieving stresses.

3.3.1 Experiment Description

Figure 17 shows a flow chart for the experiment now in progress. Czochralski and float zone wafer samples are prepared by cutting to 2cm wide ribbon-like samples. Some samples are gettered using a phosphorous getter technique while others are not gettered. Control sections are
FIGURE 17 Flow Chart for Stress-Gettering Experiments
retained for each wafer which experience no processing. SPV measurements are made for lifetime evaluation at various stages of the experiment.

Ultimately, each sample is to experience three thermal environments: 1) a stationary laser melt for one minute and then cooled rapidly, 2) insertion into the linear profile furnace at 1"/min. from the "cold" side until totally within the furnace, held stationary for one minute and then withdrawn at 1"/min., and 3) a combination of 1) and 2). Figure 18 shows the temperature profiles expected for the laser and furnace along the sample; depending on the experiment, one or the other, or both of the temperature contributions would exist.

If the furnace had an ideal thermal profile, it would be hoped that process 2) would cause no stresses and therefore low dislocation densities but would nevertheless experience a temperature profile. Process 1) would exhibit the worst thermal environment while process 3) would in some way (not very well though) approximate growth conditions.

3.3.2 Results

The experiment is only partly completed at this time but some observations have been made already:

- Temperatures and dislocation densities similar to RTR growth conditions, but not involving regrowth, result in similar diffusion lengths to those of ribbons.
- The linear profile furnace (as profiled for these experiments) did not relieve or prevent stresses either due to its own heat or due to the laser and furnace environment.
LASER/FURNACE TEMPERATURE PROFILES

POSITION (mm)

FIGURE 18: THERMAL PROFILES
"LASER ONLY" EXPERIMENTAL RESULTS

FIGURE 19: LASER ONLY: DISLOCATION AND SPV
Dislocation densities similar to that of the worst regions of RTR ribbons can be generated in single crystal material even with the furnace. Consequently, at present, stress relief is being effected but stress prevention is not.

Even relatively low temperatures (=700°C) cause significant reductions in lifetime.

Figure 19 is an example of a "laser only" experiment. Dislocations are generated near the melt but rapidly disappear with distance from the melt. Figure 19 also indicates diffusion length measurements at corresponding points of the sample. Note the correlation of very short diffusion lengths with dislocation density but then a plateau of reduction occurs well beyond observation of dislocations. This region, would have encountered high temperatures, but mostly below 700°C; only where the sample was clamped are the initial diffusion lengths of 90-110μm approached.

Figure 20 illustrates a "laser + furnace" experiment. Note the peak in dislocations at a point between the laser melt and the furnace peak; this is intuitive if one expects a temperature dip between the furnace and laser melt region - this would be a maximum stress region. Dislocations occur for some distance from the melt also since stress relief can occur over a greater distance due to the higher temperatures. Figure 20 again also illustrates diffusion lengths for this sample. Again, significant degradation occurs even in areas free of dislocations but experiencing high temperatures.

Figure 21 exhibits the stresses, measured by birefringence analysis, across the sample at the point of maximum dislocations. On the same figure is a plot of the measured dislocation densities across the sample; the correlation is evident: maxima of residual stresses corresponds to maximum stress relief (generation of dislocations) at higher temperatures.
"LASER PLUS FURNACE" EXPERIMENTAL RESULTS

FIGURE 20: LASER & FURNACE -- DISLOCATIONS AND SPV
STRESS-DISLOCATION DISTRIBUTIONS

FIGURE 21: STRESS DISLOCATION CORRELATION

32
4.0 PROBLEMS

No problems limiting progress are apparent at present.

5.0 PLANS

Fabrication, assembly and testing of various components of the new RTR apparatus will continue during the first portion of the next quarter with actual operations beginning in mid August. Once operations of the RTR #2 apparatus have begun, efforts will be made to compare performance of the two laser systems and to achieve new levels of performance. Attempts will be made to grow wide (5 - 7.5 cm) samples at high velocities in order to ascertain the nature of growth limitations for the new apparatus.

Theoretical and experimental stress analyses will continue. Various thermal profile modification techniques will be modeled and attempts made to attain lower residual stresses and reduce dislocation densities. Characterization of ribbons and fabrication of solar cells will continue with increased emphasis on analysis and process development for increased solar cell efficiency.

6.0 NEW TECHNOLOGY

No new technology items were uncovered during this report period.

7.0 PROGRAM EXPENDITURES

The following are the manhours and costs expended in the performance of the program through the month of May.
1. MANHOURS

<table>
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<tr>
<th>Previous Expenditures</th>
<th>Current Expenditures</th>
<th>Cumulative Expenditures</th>
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<td>974</td>
<td>10353</td>
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2. FUNDS

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<th>Previous Expenditures</th>
<th>Current Expenditures</th>
<th>Cumulative Expenditures</th>
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</thead>
<tbody>
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<td>372898</td>
<td>42050</td>
<td>414948</td>
</tr>
</tbody>
</table>

Figures 22 and 23 depict graphically the hours and costs expended by month.

8.0 MILESTONES

Activities associated with the total program are shown in the Milestone Chart Figure 24.

9.0 ENGINEERING DRAWINGS

Included in the appendix are drawings of the improved ribbon transport stage and preliminary drawings of components for the RTR apparatus.
HOURS EXPENDED BY THE MONTH

JPL Contract No. 954376
MOTOROLA Project 2325

-Dashed Expenditures

---Actual Expenditures

Figure 22
COSTS EXPENDED BY THE MONTH

JPL Contract No. 954376
MOTOROLA Project 2325

--- Scheduled Expenditures

--- Actual Expenditures

Figure 23

MONTHS OF PROGRAM

A  M  J  J  A  S  O  N  D  J  F  M  A
1977 1978
<table>
<thead>
<tr>
<th>TASK</th>
<th>1977</th>
<th>1978</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MAR</td>
<td>APR</td>
</tr>
<tr>
<td>No. of Weeks</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>(9) Operate (Modified) Model 1 RTR Apparatus</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>(10) Design &amp; Build Model 2 RTR Apparatus</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>(11) Support Design Performance Review</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>(12) Operate/Modify Model 2 + Theory</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>(13) Operate/Modify Model 1 + Theory</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>(14) Thermal Stress Experiments + Theory</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>(15) Provide Ribbon Samples</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>(16) Ribbon characterization/Tests</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>(17) Solar Cell Fabrication</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>(18) Solar Cell performance improvement</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>(19) RTR Economic Analysis</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>(20) Support for Meetings</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>(21) Documentation</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Initial Work Breakdown Structure</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Initial Baseline Cost Estimate</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Financial Management Reports</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Initial Program Plan</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Monthly Technical Progress Reports</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Quarterly Reports</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Interim Report</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Annual Report</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Draft Final Report</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Phase I &amp; Phase II Laboratory Notebooks</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

Figure 24 - Milestone Chart
ENGINEERING DRAWINGS
Drill + Tap
6-32 Thru.

Drill + C.S.A.
#6 Flat Head Screw - Flush
2 Places - This Side

Mat. S.S.
2 Reg

Guide Clamp Sketch 1
P. Lincoln 5/12
4/30/37

#23 Drill

Original Page Is Poor Quality
Furnace Mount
1.004
1.008
DIA

TAP \( \frac{1}{4} \)-20UNC x .50 DEEP
4 PLACES

1.75
1.250
.625

1.50
.75

TAP #10-32 UNF

MATERIAL: GOGI-TG ALUM.

TOLERANCE:
.XX ± .02
.XXX ± .005

ANCHOR BLOCK

K. TROUP 3-17-77 SCALE: 1/1

PART 3
.06 x 45° CHAMFER BOTH ENDS

1.000 ± .002 DIA

10.00

MATERIAL: GOG1-TG ALUM.
TOLERANCE:
.005 ± .02

VERT POST
K. TROUP 3-22-77 SCALE: 1/2
PART 4
1.38 2.81±.010 DIA
G'TAP 1-20UNC TO .06 REF. SLOT

TAP \( \frac{1}{4} \)-20UNC TO .06 REF SLOT

.281±.010 DIA TO .06 REF. SLOT

1.006-1.012 DIA

MATERIAL: G0GI-TG ALUM.
TOLERANCE: .XX ± .02

LOCK COLLAR

K. TROOP 3-18-77 SCALE: 1/1
PART 5
2.81 ± .010 dia to .06 ref slot

.88

.69

TAP \( \frac{1}{4} \)-20UNC to .06 ref slot

.46

.69

1.94

.75

.38

.75

.31

1.25-.129 dia thru for \( \frac{1}{8} \) roll pin \times .75 lg

1.006-1.012 dia thru

.500-.501 dia to 1.009 ref bore

MATERIAL: G061-T6 ALUM.

TOLERANCE:

\( .XX \pm .02 \)

\( .XXX \pm .005 \)

HORIZ. PIVOT ARM

K. TROUP 3-18-77 SCALE: 1/1

PART 6
.03 x 45° CHAMFER BOTH ENDS

.4997 +.0000 -.0002 DIA.

1.062

.125-.129 DIA THRU FOR 1/8 ROLL PIN x .75 LG.

1.56

MATERIAL: TYPE 303 S.S.
TOLERANCE: .XX ± .02
VERT. PIVOT SHAFT
K. TROUP 3-22-77 SCALE: 1/1
PART 7
\( \frac{1}{4} \)-20 UNC TAP TO 0.6 REF SLOT

0.281 ± 0.010 DIA TO 0.6 REF SLOT 2 PLACES

0.50 - 0.75 
2.50

VERT. PIVOT ARM

MATERIAL: GOGI-TG ALUM.
TOLERANCE: .XX ± .02

K. TROUP 3-21-77 SCALE: 1/1

PART 8
MATERIAL: 6061-T6 ALUM.
TOLERANCE:
XX ± .02
XXX ± .005

BASE PLATE
K. TROUP 3-18-77 SCALE: 1/2
PART 1
.50 TYP

.50 STOCK

.281 ± .010
2 PLACES

1.875

1.250

.281 ± .010 DIA THRU C'BORE .406 ± .010 DIA.
.28 DEEP
4 PLACES

MATERIAL: 6061-T6 ALUM.

TOLERANCE:
.XX ± .02
.XXX ± .005

ANCHOR PLATE
K. TROUP 3-18-77 SCALE: 1/2

PART 2
TAP 1/4-20 UNC TO .06 REF SLOT

.281±.010 DIA TO .06 REF SLOT

.500-.501 DIA THRU

.125-.129 DIA THRU FOR 1/8 ROLL PIN x .75 LG.

MATERIAL: 6061-T6 ALUM.

TOLERANCE: .XX±.02

SUPPORT PIVOT

K.TROUP 3-21-77 SCALE: 1/1

PART 10
TYP

18 GAGE STOCK
TYPE 302 OR 304 S.S.

.05 R

2.00

.75

SECTION A-A TYPICAL BOTH SIDES AND END

TOLERANCE: .0002

FURNACE SUPPORT
K.TROUP 3-22-77 SCALE: 1/1
PART 11
.03 x 45° CHAMFER BOTH ENDS

.4997 +.0000
-.0002 DIA.

1.125

2.25

.125-.129 DIA THRU FOR 1/8 ROLL PIN x .75 LG.

MATERIAL: TYPE 303 S.S.
TOLERANCE:
XXX ± .02
XXX ± .005

SUPPORT PIVOT SHAFT
K.TROUP 3-22-77 SCALE: 1/1

PART 9
New RTR Apparatus
3" COLUMN FLANGE

9/32 (.281) D. DRILL.
3/4" D. C'BORE TO
FLAT FACE.
4 HOLES

REWORK POWERMATIC
3" FLANGE
TOP PLATE MOUNT BRACKET

REWORK POWERMATIC PRODUCTION TABLE

3/32 (.516) D.
DRILL.
1.0 D. C' BORE
TO FLAT FACE
FROM OTHER SIDE.
4 HOLES.
WEB MINIMUM CLEARANCE AT CENTER HOLE CUTOUT.

SEE TABLE TOP DRAWING, R-0252-77

SCALE 1/2 = 1"
HORIZONTAL AIR RELIEF SLOT

- 3" LONG HYPO. TUBING FOR AIR INLET EA. PIECE

.012 WIDE X .040 DP. SLOT FOR TRACKING SILICON RIBBON .01 THIS PIECE ONLY

4-40 MOUNTING BOLTS (4) PLACES EA. PIECE

DOVER INSTRUMENTS
MOTOROLA RIBBON GUIDE
SCALE: FULL 4/1/77 W3
SKETCH #44
TOLERANCE:

XX ± .015
XXX ± .005

DRIVE ROLLER
K. TROUPE 3-30-77 SCALE: 1/1
SKO33177-7
- **RIBBON GUIDE**

**Fixed Edge Stop**

- **RIBBON, 0.50 WIDE**

- **Fixed Clearance, Flange Ball Bearings**

- **Spring Loaded Edge Ball Bearing**

**Scale 4:1**
SIMMONS FASTENER CORP.
LINK LOCK FASTENER
MEDIUM DUTY
450 LBS PULL DOWN
6 REQ.

COVER FASTENER
R-0279-77
BEACkET- VALVE

.203 Dia.
4 Holes

.15

4.00

2.87

.15

1.25

10°

.09 THICK

Glen Buday 4-22-77

RO255-77-G
NOTE - BREAK ALL CORNERS

CLAMP

TOL. .002
.005

MAT'L - STN STL

DRAWN BY: G. BUCAY 4-21-77

R-0255-5
NOTE - BREAK ALL CORNERS

MOUNTING BRACKET
CYLINDER
TOL. .005
MATERIAL - ALUM 5052H-32
.09 THICK
DRAWN BY: G. BUDAY 4-21-77
R-0255-77-4
SUPPORT BLOCK

NOTE: BREAK ALL CORNERS

R-0255-77-2
NOTE: BREAK ALL SHARP CORNERS
1. BLANCHARD GRIND FINISH. (TOP SURFACE ONLY) BEAD OR SAID BLAST AFTER GRINDING.

NOTE:

SHARP CORNER

-0.281 DIA. THRU C'SINK @ 82° 0.18 DR. FOR 1/4 FLAT HD. MACH SCR.

TOP SURFACE

SEE NOTE #1

SHARP CORNER

-3.00 TYP

.50 STK

.25 TYP

118.010

-4.00 TYP

4.00 TYP

100 TYP

13.000 TYP

11.000 TYP

24.000 TYP

35.000 TYP

118.010

MATERIAL:
COLD ROLLED STEEL

STOCK:

UNLESS OTHERWISE SPECIFIED, TOLERANCES:
INCHES: X1.000, XXX1.000
MILLISECONDS: XX1.000

ANGULAR ±/
AND ALL MACHINED SURFACES

FEATURE CONTROL SYMBOLS PER ANSI Y14.5

SHARP ALL SHARP EDGES AND CORNERS REMOVE EDGES.

UNDERLINED ITEMS NOT TO SCALE

MOTOROLA INC.
Discrete Semiconductor Division

TABLE TOP MIDDLE SECTION

NOTE:

NEXT ASSEMBLY USED ON APPLICATION

PROJECT IN USE

REVISIONS

REASON NO.

CHANGE

DATE

BY

KENP
1. BLANCHARD GRIND FINISH (TOP SURFACE ONLY), BEAT OR SAND BLAST AFTER GRINDING.

NOTE:

- .25 TYP
- .50 STK

- SHARP CORNER
- .25 TYP
- 1.00

- 10.000
- 1.00

- .25 TYP
- .50 STK

- 14 PLS.

- 43.50 TYP

- 21.75 TYP

- 35.00 TYP

- 1.00

- 7.00 TYP

- 36.000 TYP

- 2.50 TYP

- 12.00

- 1.00

- 118.010

- .50 TYP

- 40.00

- .020

- .50 DP

- V surfaces

- TOP SURFACE

- SEE NOTE #1

- SHARP CORNER

- .281 DIA. EC SINK @ 82° .18 DP FOR ¼ FLAT RD. MACH. SCR.

- 6 PLS.

- UNLESS OTHERWISE SPECIFIED, TOLERANCES

- COLD ROLLED STEEL

- MATERIAL

- TOLERANCES

- MILLIMETERS X .01 = MM X .005

- ANGULAR ± 3º

- 1/16 AND ALL MACHINED

- V SURFACES

- FEATURE CONTROL SYMBOLS

- PER ANSI Y14.5

- BREAK ALL SHARP EDGES AND CORNERS, REMOVE BURRS.

- UNDERLINED DIM NOT TO SCALE.

- THIRD ANGLE ORTHOGRAPHIC

- PROJECTION IS USED.

- MCWORLA INC.

- Discrete Semiconductor Division

- TITLE:

- TABLE TOP

- RIGHT/LEFT SIDE

- DRAWING

- C 04713

- R-0272-77-1

- SIZE

- CODE IDENT. NO.

- SCALE

- SHEET I OF 1
1. Blanchard grind finish (top surface only), bead or sand blast after grinding.

Note:
UNLESS OTHERWISE SPECIFIED
TOLERANCES:
INCHES XXXX X XXXX X XXXX
MILLIMETERS XXXX X XXXX X XXXX
ANGULAR L X X X X
SURFACES:
\[ \sqrt{X} \] SMOOTH ALL MACHINED
FEATURE CONTROL SYMBOLS
PER ANSI Y14.5
SHARP ALL SHARP EDGES AND CORNERS, REMOVE RIMS.

NOTE:

MATERIAL
COLD ROLLED STEEL

HEAT TREAT
APPLIED FINISH
SEE NOTE #1

TITLE:
TABLE TOP
CENTER MIDDLE SECTION

REVISIONS

REV\# NO CHANGE DATE BY ENGR\n
MOTOROLA INC.
Discrete Semiconductor Division

SHAPE CODE

NOTE:

1. BLANCHARD GRIND FINISH CTOP SURFACE ONLY, READ OR SAND BLAST AFTER GRINDING.

NOTE:

2. BEND DIAMETER 1/2 X 0.261 FOR 1/4 FLAT NO. MAG. 12 LBS.

NOTE:

3. SHARP CORNER SEE NOTE #1

NOTE:

4. 281 DIA. THRU C'SINK @ 82° 1.18 DR. FOR 1/4 FLAT NO. MAG. 12 LBS.

NOTE:

5. 1.50 TYP

NOTE:

6. 16.75 TYP

NOTE:

7. 33.5C TYP

NOTE:

8. 36.00 TYP
NOTES:

1. BLANCHARD GRIND FINISH (TOP SURFACE ONLY).
   BEAD OR SAND BLAST AFTER GRINDING.
ORIGINAL PAGE IS OF POOR QUALITY

SECTION A-A

1. BLANCHARD GRIND FINISH
(TOP SURFACE ONLY), B virtual OR SAND BLAST AFTER GRINDING.

NOTE:
SIDE SUPPORT

MATERIAL
6061-T6 AL.

HEAT TREAT

APPLIED FINISH

UNLESS OTHERWISE SPECIFIED, TOLERANCES:
INCHES .001 .002 .006
MILLIMETERS .025 .02 .15

AMBASSADOR .0625 RMS ALL MACHINED SURFACES

FEATURE CONTROL SYMBOLS PER ANSI Y14.9

BREAK ALL SHARP EDGES AND CORNERS, REMOVE BURRS.

UNDERLINED DIMS NOT TO SCALE.

THIRD ANGLE ORTHOGRAPHIC PROJECTION IS USED.

REVISION!
R[REV NO.
N0.
CHANGE
GATE s率领.

A MOTOROLA INC.
Discrete Semiconductor Division

SIDE SUPPORT

A 04713 R-0272-77-10
SECTION A-A

UNLESS OTHERWISE SPECIFIED, TOLERANCES:
- INCHES: ± .02
- MILLIMETERS: ± 0.05
- ANGULAR: ± 0.7°
- C37: RMS ALL MACHINED SURFACES
- FEATURE CONTROL SYMBOLS: PER ANSI Y14.5
- BREAK ALL SHARP EDGES AND CORNERS, REMOVE BURRS
- UNDERLINED DATA NOT TO SCALE
- THIRD ANGLE ORTHOGRAPHIC PROJECTION IS USED.

MATERIAL: 6061-T6 AL

HEAT TREAT
APPLIED FINISH

TITLE: HOLD DOWN RING

MOTOROLA INC.
Discrete Semiconductor Division

NOTES
- "UNLESS OTHERWISE SPECIFIED, TOLERANCES..."
- "DRAWN BY R. KASSLER II"
- "CHECKED BY "
- "APPROVED BY "
- "SCALE: FULL"
- "DRAWING NO. R-0278-77-15"

CHECKBOX FOR "USE IN AN APPLICATION"
.03 X 45° CHAMF BOTH ENDS

.125$^{+0.003}_{-0.000}$ DIA.

.374 DIA

.25

.50

.03 X 45° CHAMF BOTH ENDS

*4-40 UNC TAP THRU TO BORE

UNLESS OTHERWISE SPECIFIED, TOLERANCES:
INCHES $XX \pm 0.02 \times XX \pm 0.005$
MILLIMETERS $XX \pm 0.02 \times XX \pm 0.012$

ANGULAR $\pm 0.01$

$\leq 3$ RMS ALL MACHINED SURFACES.

FEATURE CONTROL SYMBOLS PER ANSI Y14.5

BREAK ALL SHARP EDGES AND CORNERS, REMOVE BURRS.

UNDERLINED DM NOT TO SCALE.

THIRD ANGLE ORTHOGRAPHIC PROJECTION IS USED.

MATERIAL
HALF-HARD BRASS

HEAT TREAT

APPLIED FINISH

DRAWN BY R. KASSER II 6/7/72

CHECKED DATE

APPROVED DATE

MOTOROLA INC.
Discrete Semiconductor Division

DRAWING NO.
R-0272-77-12

SIZE CODE IDENT. NO.
B 04713