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BEAM LEAD DEVICE
TEMPERATURE TESTING

PDO 6984879, Final Report

L. W. Brown, Project Leader

Project Team:
E. P. Benedict

Published August 1976

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Final Report

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Division**

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BEAM LEAD DEVICE TEMPERATURE TESTING

BDX-613-1275, UNCLASSIFIED Final Report, Published August 1976

Prepared by L. W. Brown, D/863, under PDO 6984879

The ability to perform 100 percent electrical testing (probe testing) across the temperature range from 0 to 50°C was developed and correlation to -55 and 100°C performance was established. Probe testing to 100°C is not possible at this time because a wax, compatible with established beam lead device processes and able to withstand such temperatures, is not available.

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SUMMARY

The ability to perform 100-percent electrical probe testing of beam lead devices (BLD) at temperatures from 0 to 50°C was developed. Correlation of probe test results to bonded sample test results from -55 to 100°C was established for some parameters on transistors, diodes, and zener diodes.

The tests performed on transistors included collector-to-emitter leakage, collector-to-base leakage, current gain, and collector-emitter saturation voltages. Reverse leakage current tests were performed on diodes and zener diodes in addition to forward voltage drop on diodes and zener voltage on zener diodes.

It was determined from these tests that, in nearly all cases, probe testing can be performed at room temperature to assure a limit at temperature extremes once the exact temperature dependence of the parameter is known for a lot of devices. No waxes compatible with either vendor or Bendix Kansas City Division BLD processing are presently available which will allow testing at temperatures above 50°C.

DISCUSSION

SCOPE AND PURPOSE

The objective of this process development project is to establish the capability to perform 100-percent electrical testing (probe testing) on beam lead devices at temperatures other than 25°C. This capability, if practical, will alleviate the present situation whereby only a sample of devices from each lot is subjected to extreme temperature testing.

Work included the following items:

- Develop a wax capable of holding dice in the as-etched arrays so probing may be accomplished at temperatures exceeding 100°C;
- Evaluate limitations of room temperature to high temperature and room temperature to low temperature correlation factors;
- Develop a method of using heated and cooled chucks for probe testing of as-etched arrays and wafers before etch separation; and
- Evaluate the compatibility of the developed processes to those now in use.

ACTIVITY

Wax Evaluation

The ability to probe-test at temperatures other than room ambient had not been demonstrated at the outset of this study. Also, the waxes used by the manufacturers for holding BLDs in place during and after etch separation have a softening point just over 75°C. This limits possible test temperatures to far below 100°C. This is supported by the fact that chuck temperatures used on the Bendix Kansas City Division Receiving Inspection automatic BLD handler are normally between 73 and 78°C.

Investigations into alternative waxes were based on the following requirements:

- Wax must have a softening point of 125 to 150°C;
- Wax should volatilize between 150 and 200°C;
- Wax should withstand photoresist bake at 125°C for 1 hour;

- Wax must withstand a variety of etchants, including hydrofluoric acid, nitric acid, acetic acid, ammonium fluoride, sulfuric acid, sodium hydroxide, and xylene; and
- The shear strength of a thin layer of wax between the silicon wafer and the sapphire disc must be sufficient to allow wafer thindown grinding or polishing without breakage or other damage.

Six waxes were selected for evaluation. These were the only waxes revealed by a product literature search carried out by Materials Engineering with properties close to these requirements. The waxes along with their manufacturer and, if known, their composition are listed below.

- Acrawax C: N,N'-ethylene-bis-stearamide, Glyco Chemical, Inc.
- Lipowax C: Ross Waxes, Inc.
- Paraffin: Hydrocarbons from petroleum, Ross Waxes, Inc.
- Rosswax 160: Ross Waxes, Inc.
- Microwax: Hydrocarbons from petroleum, Ross Waxes, Inc.
- Polywax 2000: Ethylene homopolymer, Petrolite Corporation

Melting point, softening point, and volatilization temperature measurements were made by Materials Engineering. The melting points were determined using a differential scanning calorimeter. This method measures the endothermic transition of melting as a function of temperature. The melting temperature shown indicates the onset of melting because the waxes are synthetic and often have a melting temperature range rather than an exact melting point. The softening points were determined by using thermomechanical analysis and duplicate samples exhibited good reproducibility. The volatilization temperature range was determined by using a thermogravimetric analyzer. Results were obtained by plotting the percent weight loss of the sample as a function of increasing temperatures. Two temperatures, the point at which initial weight loss occurred and the point at which weight loss was 100 percent, are listed in Table 1.

It is obvious, upon comparing the data in Table 1 with the requirements the waxes were to meet, that the desired qualities were not obtained on the waxes evaluated. The softening points are much lower than the 125°C minimum desired and the volatilization temperature is much higher than the 200°C maximum desired. Although a good match of the desired qualities was not achieved in the wax study, some work was undertaken at the facilities of

two different BLD suppliers. The attempts to use the waxes were not successful. The waxes were too hard and brittle after application of the silicon wafer to the sapphire disc to allow thindown grinding of the wafer. The wax powdered when lateral stress was applied to grind the silicon wafer down to the proper thickness.

Apparently, if a wax capable of the unusual properties initially required in this study is necessary, a special development effort will be required by a wax manufacturer.

Table 1. Wax Temperature Parameters

Sample	Melting Point (°C)	Softening Temperature (°C)	Volatilization Temperature (°C)
Acrowax C	140	70.5	208 to 572
Lipowax C	138	69.8	210 to 570
Paraffin Wax	53	--	173 to 525
Rosswax 160	150	75.2	200 to 590
Microwax	58	--	183 to 520
Polywax 2000	122	74.0	236 to 550

Temperature Testing of Devices

In order to evaluate the effects and limitations of electrical probe testing at temperatures different from room ambient, as-etched arrays of the various device types were obtained: two as-etched arrays of SA2209 diodes (B2D3600 general purpose diode), two as-etched arrays of SA2221 zener diodes (B2D752A, 5.6-volt zener diode), one as-etched array of SA2211 transistors (B2T2484 NPN transistor), and one as-etched array of SA2212 transistors (BT2484 NPN transistor from an alternate supplier). The arrays were mounted in waxes which are being used for mounting and etch separation by the suppliers.

The arrays were probe tested at temperatures of 0, 10, room ambient, 30, and 50°C. A Thermospot thermal chuck, capable of maintaining its temperature within $\pm 5^\circ\text{C}$, was adapted to a TAC PS100 probe system. The probe system was interfaced with a Fairchild 600 semiconductor test system. Probe data was logged on a minimum of 200 good devices per array. Histograms were generated and means were calculated. Traceability was maintained from device location in the array to each data point. The tests

made were those normally probe tested on each of the device types at room temperature. No probe tests were carried out above 50°C in order to assure a margin of safety between the test temperature and the softening temperature of the wax.

After probe testing the arrays at all five temperatures, a minimum of 30 devices was removed from each array. The devices were bonded to TO-18 test headers to allow a broader range to temperature testing. The canned devices were placed in a temperature controlled environmental chamber and electrically tested using the Fairchild 600 test system. The devices were tested at temperatures of -55, -25, 0, 10, room ambient, 30, 50, 75, and 100°C. The objective of testing the devices at several temperatures was to maximize the possibility of correlation of results between the probed and canned device data.

Tests performed on the SA2209 diode were leakage current (I_R) at 40 volts, and forward voltage drop (V_F) at 1 mA and 10 mA.

Because leakage current (I_R) readings were not taken in very small temperature increments, a large step is present in the graphs for both lots of SA2209s just below room ambient temperature. This step or discontinuity is caused by the formation of moisture on the devices at and below the dew point causing a parallel leakage path around the junction. It may be noted, from Figure 1 and Figure 2, that a degree of correlation of the mean leakage values of the probed and canned devices exists between room ambient temperature and 50°C. This correlation is not, however, the same on the two lots in question. In one case, the slope of the probe results is more steep than the slope of the canned devices (Lot 917, Figure 1), and in the other instance (Lot 485, Figure 2) the reverse is true. This is at least partially due to a difference in the population of the samples (30 canned as opposed to 200 probed samples). In any case, given the slope of the canned sample leakage curve due to temperature, probe limits may be established for room temperature or elevated temperature testing. The advantage of elevated temperature testing would be greater assurance of removing freak failures which might not follow the established curve.

Forward voltage drop (V_F) tests at 1 mA (Figures 3 and 4) show excellent correlation between the canned and probed results; however, the probe results tended to have a greater range of values than did the canned devices. This may be due to either or both of the following items: difference in device population of 30 to 200 and, the fact that better ohmic contact can be made between a packaged device and the test equipment than can be made between a probe point and a gold beam lead. No advantage to probe testing for V_F at a temperature other than room ambient is apparent from the information in Figures 3 and 4.

Figure 1. SA2209 I_R at 40V (Lot 917)

Figure 2. SA2209 I_R at 40V (Lot 485)

Figure 3. SA2209 V_F at 1 mA (Lot 917)

Figure 4. SA2209 V_F at 1 mA (Lot 485)

Forward voltage drop (V_F) tests at 10 mA (Figures 5 and 6) show very good correlation between probed and canned results. The only unusual effect was a significant spreading of the maximum and minimum values as taken by the probe test at 0°C on Lot 485 (Figure 6). This spreading was not present at any other temperature. No data is available to indicate why this might have happened, but it is possible that the formation of ice crystals on the beams caused the probe points to sometimes make poor contact. As with 1 mA V_F testing, no advantage to probe testing at a temperature other than room ambient is apparent from Figures 5 and 6.

Breakdown voltage testing was performed on the canned devices, but was not performed on the probed devices because difficulty has been experienced with devices being overstressed during breakdown probe testing. This problem is due to occasional poor ohmic contact allowing the voltage to greatly exceed the limit of the junction. When this happens, arcover from the probe to the beam occurs and destroys the junction.

Tests performed on the SA2211 and SA2212 transistors included: collector-base leakage current (I_{CBO}), emitter-base leakage current (I_{EBO}), collector-emitter saturation voltage, $V_{CE}(\text{Sat})$, base-emitter voltage V_{BEon} , and DC current gain (h_{FE}) at 10 microamperes, 500 microamperes, and 10 milliamperes.

Collector-emitter saturation voltage, $V_{CE}(\text{Sat})$, testing on the SA2211 and SA2212 yielded mixed results. The values of $V_{CE}(\text{Sat})$ obtained on the SA2211 were reasonably linear from 0°C to 100°C on the canned sample and from 0°C to 50°C on the probed sample (Figure 7). The slopes of the curves are the same, but probed values were higher than those for canned devices. This is primarily due to poor probe contacting on some devices. Below 0°C, the slope of $V_{CE}(\text{Sat})$ versus temperature is slightly negative in sharp contrast to the remainder of the curve. There is some indication that the probed data would act the same as the canned data below 0°C, in that minimum observed readings were the same at 0 and 10°C on the probed and canned samples. The minimums differ by approximately the same amount as the means.

$V_{CE}(\text{Sat})$ results (Figure 8) for the SA2212 transistor were linear with temperature from -55 to 100°C on the canned devices. A linear trend was apparent on the probed devices from 0 to 50°C as well, but there was a much greater degree of variability in the readings. Again, as with the SA2211, probe contact resistance appears to have moved the mean upward in voltage although the whole range of values are below those taken on the SA2211.

While it appears that elevated temperature probing for $V_{CE}(\text{Sat})$ is feasible on the SA2211 and SA2212, the variability of the probe results and the performance of all devices well below the specification maximum of 0.35 volts do not make doing so advantageous unless a circuit application requires it.

Figure 5. SA2209 V_F at 10 mA (Lot 917)

Figure 6. SA2209 V_F at 10 mA (Lot 485)

Figure 7. SA2211 $V_{CE(Sat)}$ at 1 mA

Figure 8. SA2212 $V_{CE(Sat)}$ at 1 mA

Emitter-base voltage (V_{BEon}) testing on both the SA2211 and SA2212 yielded curves with nearly identical slopes from -55 to 100°C on the canned samples (Figures 9 and 10). The probed results were also similar in that the SA2211 and the SA2212 results showed slightly less slope of V_{BEon} versus temperature and had a crossover point near room ambient. Probe testing to protect desired limits of V_{BEon} appeared practical provided a control sample from the lot in question was first probe tested and then bonded and retested. The distribution is so tight on both samples tested that if limits greatly different from the observed performance were desired, yield loss would be extremely high.

Probed h_{FE} data was taken at collector currents of 10 microamperes, 500 microamperes, and 10 milliamperes across the temperature range from -55 to 100°C . SA2211 h_{FE} test data at $10\text{ }\mu\text{A}$ (Figure 11) was noticeably non-linear as predicted by published information. The probed data exhibits slightly lower means than the canned sample data, but the curves have the same shape. Data at 0°C on both the probed and canned devices was out of position or overranged due to moisture formation on the devices. The same was true for canned devices at -25°C ; however, canned device data at -55°C came back into line with that taken above 0°C .

Data on $10\text{ }\mu\text{A}$ h_{FE} for the SA2212 revealed an h_{FE} versus temperature curve which was considerably more linear than the SA2211 (Figure 12). The probe data did not follow the slope of the canned data and was spread about the mean to a slightly greater degree. As with the SA2211, probe data at 0 and 10°C and canned data at 0 and -25°C did not fall on the curve. This is attributed to moisture formation on the devices causing leakage currents which changed the observed value of h_{FE} .

The capability to predict performance of $10\text{ }\mu\text{A}$ h_{FE} at temperature extremes and to assure a given level of performance by testing at intermediate temperatures is present on the SA2211 and SA2212. As with other tests however, it appears that once the slope of the curve is known on a lot of devices, screening to certain temperature requirements can be accomplished at room temperature.

SA2211 $500\text{ }\mu\text{A}$ current gain h_{FE} tests (Figure 13) followed the general predicted curve for h_{FE} versus temperature with both the canned sample and the probed devices. The minimum readings taken by probe testing at some temperatures were much too low and appear to have caused the mean values for h_{FE} to be lower than those taken on canned samples. The curve is therefore approximately 10 percent lower for probed devices than for canned ones. This problem, however, would be eliminated by using a minimum specification limit.

The SA2212 was the first device type probe tested and data was not taken for $500\text{ }\mu\text{A}$ h_{FE} . The canned sample was tested at $500\text{ }\mu\text{A}$

Figure 9. SA2211 $V_{BE(on)}$

Figure 10. SA2212 $V_{BE(on)}$

Figure 11. SA2211 h_{FE} at $10 \mu A$

Figure 12. SA2212 h_{FE} at $10 \mu A$

Figure 13. SA2211 h_{FE} at 500 μA

for information and yielded a nearly linear h_{FE} versus temperature curve. Since corresponding probe data is not available, an attempt to draw any correlative conclusion will not be made.

Predictability of 500 μA h_{FE} performance at temperature extremes from results in the 0 to 50°C range is present on the SA2211. Probe testing at intermediate temperatures would guarantee conformance to limits at temperature extremes. It appears that, once the curve is known for a given lot of material, probing at room temperature would accomplish the same purpose except for occasional "maverick" units.

SA2211 10 mA h_{FE} testing again yielded the predicted curve contour as a function of temperature, but probed values were 10 percent below the canned device values. This was also experienced on other h_{FE} current levels for the SA2211. In all cases the room temperature probed values were very close to the room temperature canned samples while values were low at other temperatures. Figure 14 shows the h_{FE} curves at 10 mA versus temperature.

The SA2212 10 mA h_{FE} was again slightly more linear than SA2211 h_{FE} . In addition, means, maxima, and minima of the probed and canned devices were very close at all temperatures from 0 to 50°C (Figure 15).

Figure 14. SA2211 h_{FE} at 10 mA

Figure 15. SA2212 h_{FE} at 10 mA

Probe testing at intermediate temperatures for 10 mA h_{FE} seems feasible, but would appear screenable from special room temperature probe limits based upon sample testing from the lot involved. This should be true for both the SA2211 and the SA2212.

Collector-base leakage (I_{CBO}) tests on the SA2211 were acceptable at room temperature, but varied widely at both elevated and reduced temperatures. Canned sample tests exhibited higher values than did probed samples at all temperatures except room ambient. Predicted decreases in leakage current below room ambient were not observed due to moisture contamination. Increases in leakage above room temperature were unpredictable as well, and probed and canned results differed widely. Normal guard banding based upon the accepted temperature dependence of I_{CBO} is the only alternative based upon the results of this testing. The reason why results were not as predicted is either due to an additional variable like some degree of damage due to bonding or some header contamination.

Collector-base leakage (I_{CBO}) tests on SA2212 canned samples followed the predicted curves of leakage versus temperature reasonably well although a sharp offset in mean and maximum readings was noted above 25°C. Probe test results at 25 and 50°C bracketed the canned results fairly well. Results at temperatures below room ambient were very erratic due to the presence of moisture.

Setting desired leakage limits at 50°C might reduce the incidence of higher leakage failures at 100°C, but it appears that using a room temperature probe limit to assure a maximum at 100°C would be adequate.

Emitter-base leakage tests on both the SA2211 and SA2212 yielded erratic results, although canned samples appeared to follow the theoretical curve for increasing leakage with increased temperature. Probe results did not correlate well. For example, on the SA2212 leakage at 25°C ranged from 0 to 100 nA and at 30°C, from 0 to 0.11 nA.

As with other leakage measurements, results below room ambient were severely affected by moisture condensation. No conclusions other than the known temperature dependence of leakage upon temperature can be made.

Temperature testing of the SA2221 5.6 volt zener diode was performed for 20 mA and 100 μ A zener voltage and 1 volt leakage current.

Zener voltage at 20 mA was linear from -55 to 100°C on canned samples from two lots of devices (Figures 16 and 17). Probed

Figure 16. SA2221 V_Z at 20 mA (Lot SL2)

Figure 17. SA2221 V_Z at 20 mA (Lot SL3)

values approximated those obtained on canned samples, although the means were both lower by 5 percent. No reason for this difference in mean zener voltage is apparent. It is apparent that probing to assure performance at a given temperature is feasible, but there is little indication that there would be an advantage to probing at temperatures other than 25°C to assure high or low temperature performance.

Zener voltage at 100 μ A was also linear from -55 to 100°C on the canned samples. In addition, probed values of mean, maximum, and minimum were virtually identical with values obtained on the canned devices at 0, 10, room temperature, 30, and 50°C. The V_Z versus temperature curves are shown in Figures 18 and 19. It is apparent that good predictions of high and low temperature performance can be made by probing at intermediate temperatures, but the data gives no indication that any advantage would be gained over probing at room temperature.

Reverse leakage probe testing yielded 0 nA at temperatures of 0 through 50°C on Lot SL2 (Figure 20). Leakage on Lot SL3 had a minimum of 0 nA at 0 through 50°C; however, the maximum was greater than 0 nA at 0 and 10°C (Figure 21).

Results differ on the canned samples for both lots however, in that, while the minimum is still at 0 nA, the mean is from 2 to 6 nA. Maximum observed leakage on Lot SL3 went from 20 to 85 nA between -55 and 100°C; on Lot SL2 maximum leakage went from 60 to 99 nA.

From the data expressed in Figures 20 and 21, it appears that some degree of degradation was encountered due to removal from the as-etched array or due to handling or bonding. In either case, it appears that the leakage current observed in probe testing will be lower than that observed in samples which have been bonded to circuits. No advantage is apparent for probe testing at either elevated temperature or reduced temperature, given the very low leakage measurements on probe testing.

The following information was gained concerning the use of electrical probe testing from 0 to 50°C:

- Reverse leakage current and forward voltage drop testing on diodes revealed a positive correlation between probe testing and testing of devices bonded onto T0-18 headers.
- Collector-base and emitter-base leakage testing of transistors exhibited a lack of predictability between probe testing and testing of devices bonded onto T0-18 headers. Room temperature testing was the only point where canned and probed results approximated one another, and where the

Figure 18. SA2221 V_Z at 100 μA (Lot SL2)

Figure 19. SA2221 V_Z at 100 μA (Lot SL3)

Figure 20. SA2221 I_R at 1V (Lot SL2)

Figure 21. SA2221 I_R at 1V (Lot SL3)

results were within predictable limits. These results are believed to be due to a variety of factors, including moisture contamination at low temperature, some possible device damage due to bonding, possible problems with the glass filled T0-18 headers, and the chance that the devices were not representative of what would be bought using an "SA" device specification.

- Collector-emitter saturation voltage, $V_{CE}(\text{Sat})$, and base-emitter voltage, $V_{BE}(\text{on})$, testing of transistors revealed a significant degree of correlation. The SA2211 sample changed slope drastically below 10°C which diminishes predictability of low temperature performance from probe testing down to 0°C . Both samples had higher mean values when probed than when tested on T0-18 headers, apparently due to additional voltage drop at the beam-probe interface. $V_{BE}(\text{on})$ slopes for probed devices changed with temperature to a greater degree on the canned devices than on the probed devices. The effect is not believed to be due to probe contact, since that would simply shift the curve without appreciably affecting the slope.
- DC current gain h_{FE} testing of transistors revealed that predictability of results at temperature extremes from results obtained by probe testing was quite good. Higher gains at the lower temperatures at low currents tended to push the bottom of the probed device curve above that of the canned devices. This is apparently due to moisture induced leakage.
- Zener voltage testing on zener diodes showed good predictability of bonded sample results at temperature extremes from probed results at moderate temperatures. Of special interest is 100 μA zener voltage on which the means of both samples coincided to make one curve of zener voltage versus temperature across the entire -55 to 100°C range.
- Leakage current testing of zener diodes revealed a problem not obvious on the other device types tested. Probe tested leakage current exhibited a mean of approximately 0 nA to two decimal places, while the means of the bonded (canned) samples were on the order of a few nanoamperes with maximum readings as high as 84 nA at 50°C . Leakages were within established specification limits on all devices, but the differences noted indicate a potential degradation or handling phenomenon. It appears that probe testing to assure minimum leakage at some temperature on the two lots tested would not be capable of rendering the desired effect.

From the information gained on the testing conducted in this study, it is apparent that, in most cases, probe testing at

room temperature with limits suitable to assure the desired limits at -55°C , 100°C , or both are not only possible but preferred. In isolated cases, however, it may be that only a portion of the distribution would function as desired. In those cases, probe testing at intermediate temperatures could well minimize losses, but characterization of individual devices from the wafer in question both before and after bonding, would be necessary. Equipment and processes presently in use at Bendix would be readily adaptable to this process since the evaluations were carried out on virtually identical probe test equipment.

Although it is impossible to exceed 50°C by very much with the limitation imposed by the softening point of the wax, the possibility to go lower in temperature exists. Temperature chucks are available which go to -55°C ; however, with the model now in use, moisture contamination would seriously hamper probing efforts. With such a temperature chuck, an airtight cover through which dry nitrogen was continually passed would inhibit moisture condensation and allow meaningful probe testing. The temperature chuck approach used here, with or without the nitrogen purge feature, would work as well for unetched arrays (wafers) as for the as-etched arrays evaluated. In addition, the wax temperature limitation would not apply since there would be no necessity to hold devices in place in the unetched wafer.

The arrays used in this study were examined visually at the conclusion of this study. No disarray was noted due to the repeated heating of the wafers. Some of the arrays were found to have wax over the beams. It had wicked up and covered the beams during some high temperature operation. This could have been due either to the temperature probing or, more likely, due to the sample pull operation on the Bendix manual beam lead handler (Pick and Place machine). The latter is more likely because the temperature used was around 75°C , near the softening point of the wax. This wax is usually removable by careful radio frequency ashing* and should not be considered a serious drawback.

ACCOMPLISHMENTS

The following facts were revealed from this study:

- It was determined that a commercial wax superior to that now in use by the BLD suppliers is not available;

*RF ashing is a system using radio frequency energy in an enclosed system with a partial pressure of oxygen. The heating action of the RF energy in the oxygen atmosphere causes decomposition of organic compounds without melting them.

- Electrical probe testing across the temperature range from 0 to 50°C was established, and the ability to correlate those results to -55 and 100°C performance was demonstrated; and
- Probe testing at room temperature to assure limits at temperature extremes is sufficient in most cases once the temperature dependence of a lot of devices is characterized.

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R. P. Frohmberg, D/800	18
D. H. Hax, D/800	19
F. A. Spies, D/800	20
A. O. Bendure, D/842	21
J. A. Peters, D/842	22
T. A. Wiley, D/842	23
W. C. Coupland, D/863	24
E. P. Benedict, D/863	25
L. W. Brown, D/863	26-30
U. C. Brown, D/863	31
R. J. Dale, D/863	32
A. V. Grimm, D/863	33
L. W. Smith, D/863	34
J. H. Swafford, D/863	35
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