DRL 175

DOE/JPL-956205-83/4
Distribution Category UC-63

Quarterly Technical Progress Report

No. 6329-15

on the

# DEVELOPMENT OF METALLIZATION PROCESS

FSA Project, Cell and Module Formation Research Area

For the Period Ending

June 30, 1983

Contract 956205

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Approved by:

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August 1983

The JPL Flat Plate Solar Array Project is sponsored by the U.S. Department of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology by agreement between NASA and DOE.

ABSTRACT/SUMMARY

A non-lead frit paste was received from Thick Film Systems Inc. and evaluated. The results were not promising. Additional work was done on a two-step process where the bulk of the metallization is Mo/Sn but a small ohmic pad is silver. This approach was successful. A new matrix of paste formulations was developed with JPL and Electrink, Inc. personnel. A series of 12 pastes was ordered from Electrink, Inc.

## Section 2.0

## TECHNICAL DISCUSSION

A non-lead frit paste was ordered from Thick Film Associates #DP-F523. The paste was the same as the Type F paste except the new frit was substituted for the old type. Table 1 shows the characteristics of cells made with this paste. Figures 1-4 show Cells 83, 79, 81, and 85, respectively. As the time of sintering lengthened from 1.5, 5, 10, to 15 minutes at 600°C, the cells first improve as the series resistance decreases, then degrade as shunting occurs. Lower sintering temperatures led to very high series resistance and poor electrical characteristics (Figure 5). Soldering was unsuccessful on these cells.

Thick Film Systems would not supply exact formulations of their proprietary frits. Future pastes will be ordered from Electrink who have agreed to furnish exact formulations.

In view of the difficulties in soldering to the Mo/Sn pastes several experiments were conducted using a two step screen-printing procedure. One step would put down a small silver paste soldering pad and the other the Mo/Sn grid pattern.

The first experiment was done using paste F503. The cells were printed with the front metallization pattern missing the ohmic pad. The 600°C prefire at 18"/min. was then performed. Silver paste was printed on the ohmic pads overlapping the Mo/Sn paste. The cells were fired in the IR furnace at 48"/min. with an 18" zone at 400°C and a 24" zone at 750°C. The cells were next

Table 1

| Cell | Prefire | | Fire | | | $V_{oc}$ | $I_{sc}$ | $I_{500}$ |
|---|---|---|---|---|---|---|---|---|
| | Temp. | Belt | Gas | Temp. | Time | | | |
| 41082-70 | 600 | 18 | $H_2$ | 600 | 1.5 | 593 | 643 | 351 |
| 41082-79 | 600 | 18 | $H_2$ | 600 | 5.0 | 595 | 646 | 416 |
| 41082-81 | 600 | 18 | $H_2$ | 600 | 10.0 | 591 | 665 | 360 |
| 41082-85 | 600 | 18 | $H_2$ | 600 | 15.0 | 592 | 667 | 353 |
| 41082-83 | 600 | 18 | $H_2$ | 550 | 15.0 | 580 | 654 | 291 |

Figure 1

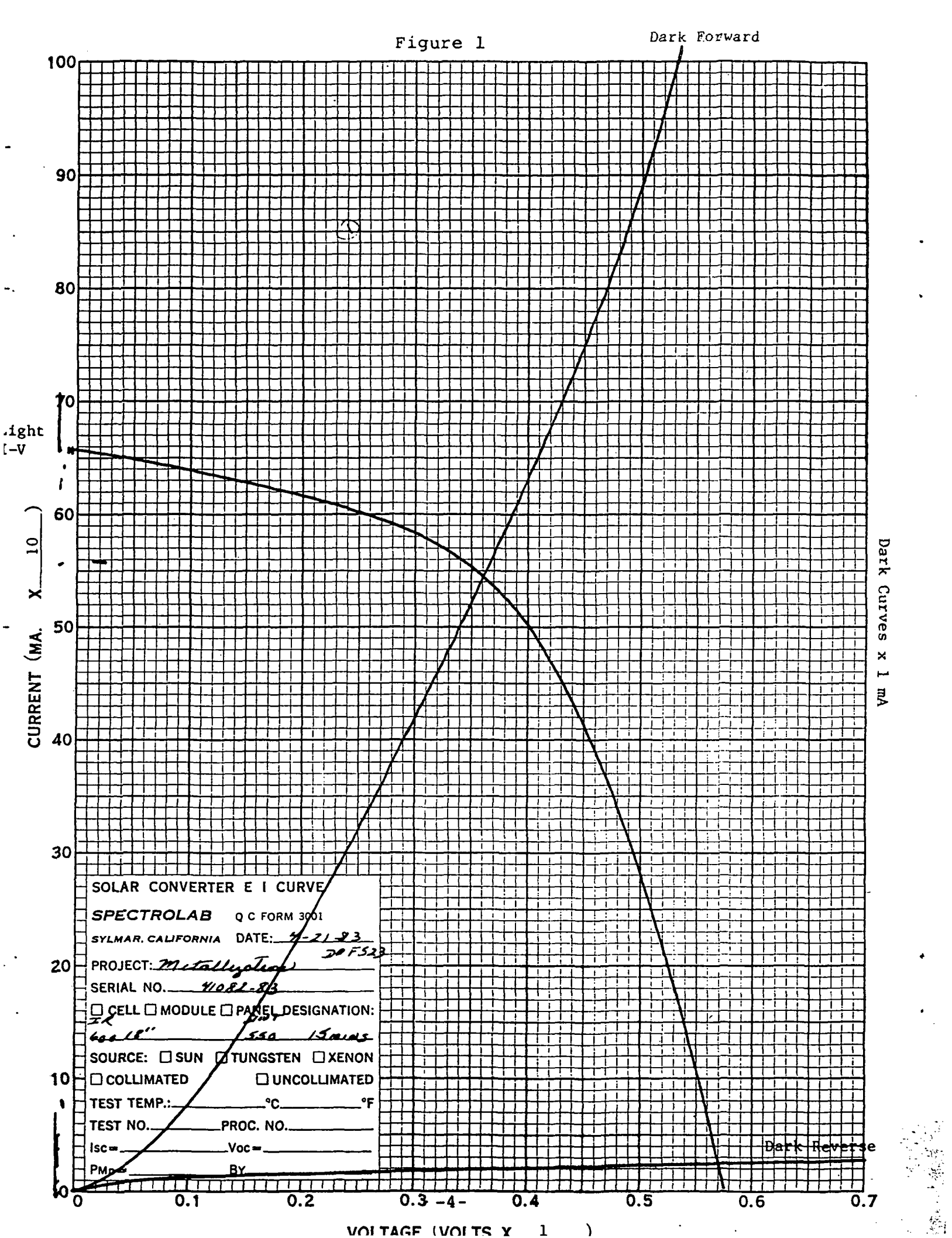

Dark Forward
100
90
80
70
60
50
40
30
20
10
0
CURRENT (MA. X 10 )
ight
[-V
Dark Curves x 1 mA
SOLAR CONVERTER E I CURVE
SPECTROLAB Q C FORM 3001
SYLMAR, CALIFORNIA DATE: 4-21-83
PROJECT: Metallization
SERIAL NO. 4081-83
☐ CELL ☐ MODULE ☐ PANEL DESIGNATION:
SOURCE: ☐ SUN ☐ TUNGSTEN ☐ XENON
☐ COLLIMATED ☐ UNCOLLIMATED
TEST TEMP.: °C °F
TEST NO. PROC. NO.
Isc= Voc=
PMax= BY
Dark Reverse
0
0.1
0.2
0.3
-4-
0.4
0.5
0.6
0.7
VOLTAGE (VOLTS X 1 )

Figure 2

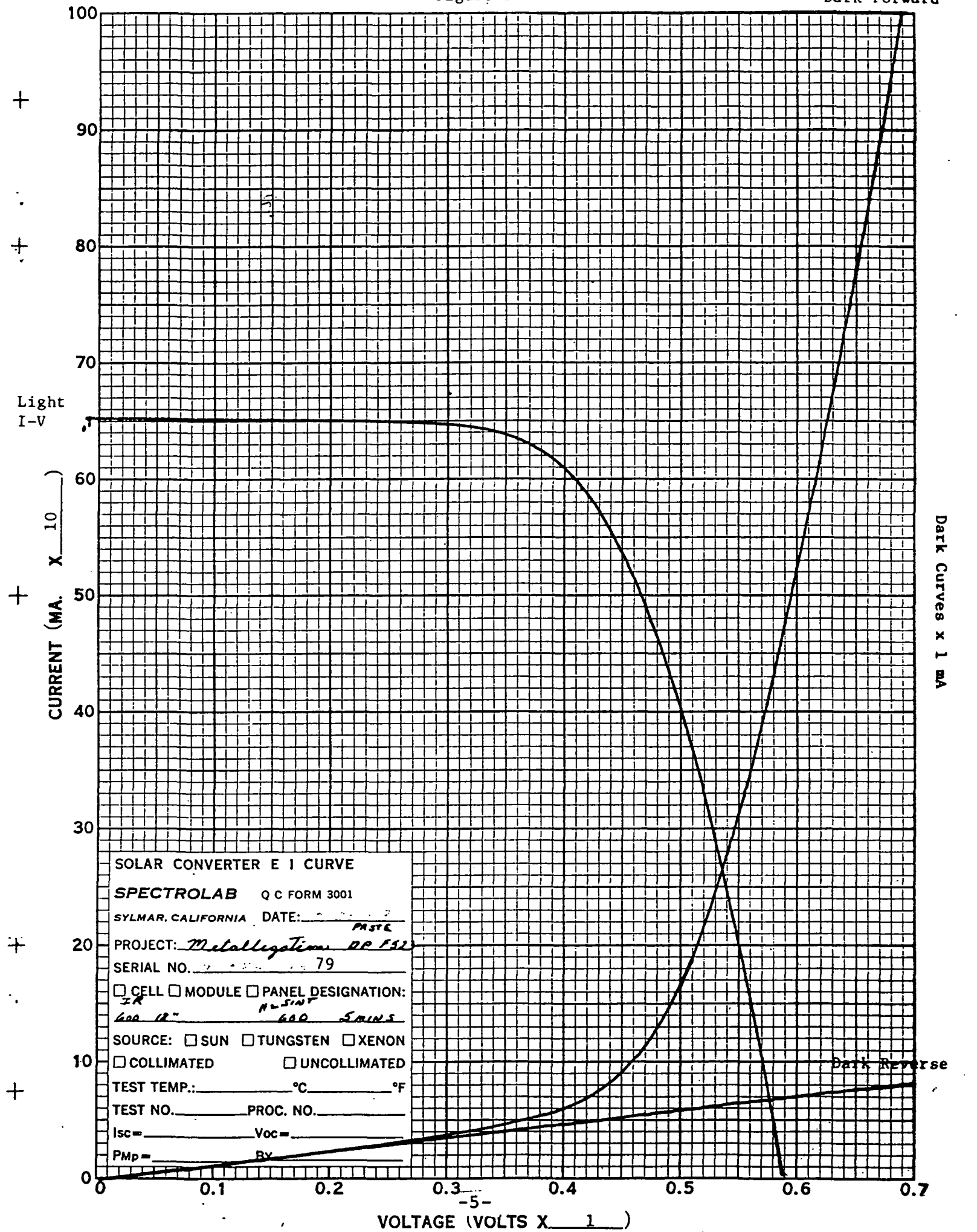

Dark Forward
Light I-V
CURRENT (MA. X 10)
Dark Curves x 1 mA
Dark Reverse
VOLTAGE (VOLTS X 1)
100
90
80
70
60
50
40
30
20
10
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
SOLAR CONVERTER E I CURVE
SPECTROLAB Q C FORM 3001
SYLMAR, CALIFORNIA DATE:
PASTE
PROJECT: Metallizations AR F523
SERIAL NO. 79
☐ CELL ☐ MODULE ☐ PANEL DESIGNATION:
IR
600 12"
N-SINT
600 5 MILS
SOURCE: ☐ SUN ☐ TUNGSTEN ☐ XENON
☐ COLLIMATED ☐ UNCOLLIMATED
TEST TEMP.: °C °F
TEST NO. PROC. NO.
Isc = Voc =
PMp = By

Figure 3

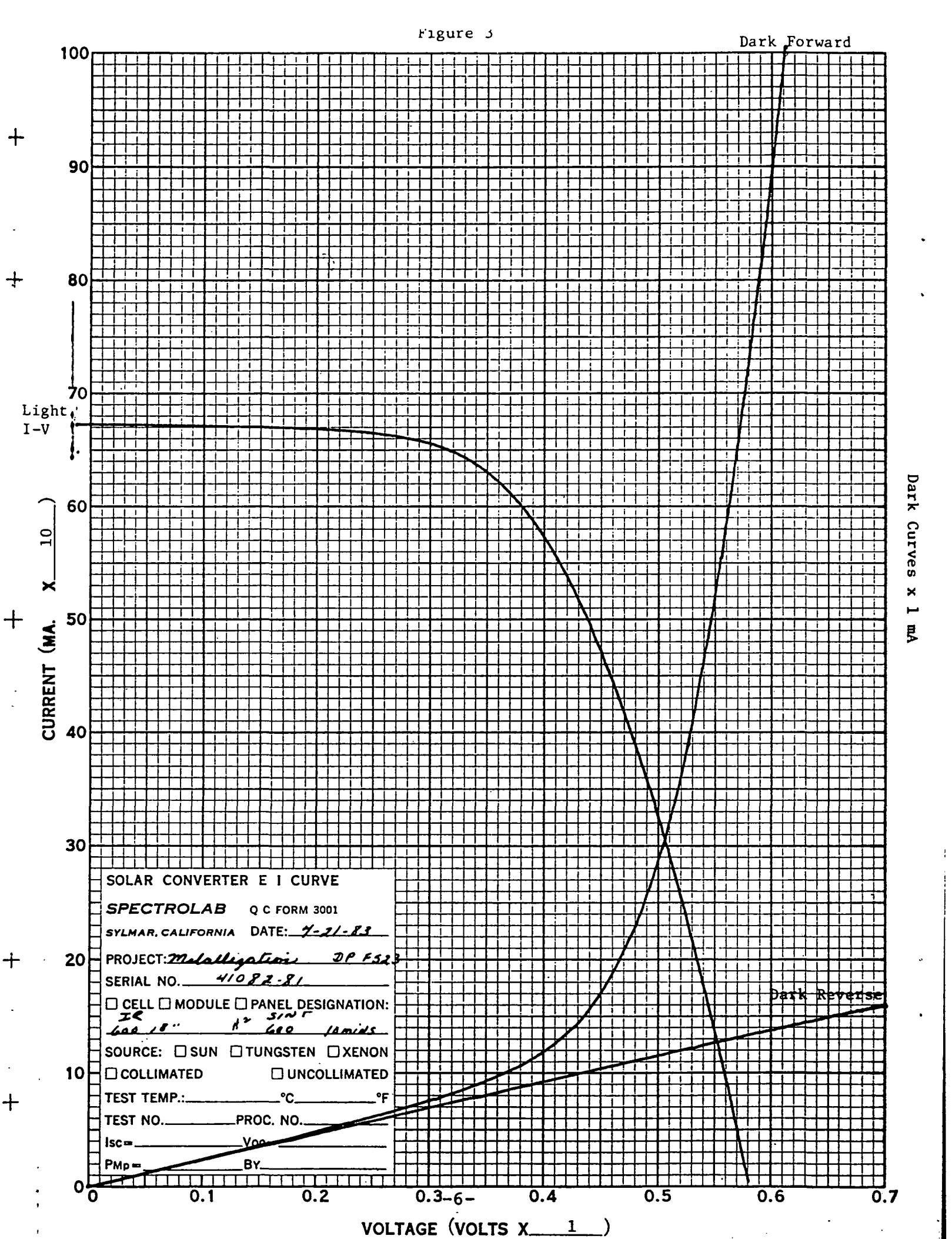

Dark Forward
Light I-V
Dark Reverse
CURRENT (MA. X 10)
VOLTAGE (VOLTS X 1)
Dark Curves x 1 mA
100
90
80
70
60
50
40
30
20
10
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
SOLAR CONVERTER E I CURVE
SPECTROLAB Q C FORM 3001
SYLMAR, CALIFORNIA DATE: 4-21-83
PROJECT: Metallization DP F523
SERIAL NO. 41082-81
☐ CELL ☐ MODULE ☐ PANEL DESIGNATION:
IR 600 18" N² SINT 600 10mins
SOURCE: ☐ SUN ☐ TUNGSTEN ☐ XENON
☐ COLLIMATED ☐ UNCOLLIMATED
TEST TEMP.: °C °F
TEST NO. PROC. NO.
Isc= Voc=
PMp= BY

Figure 4

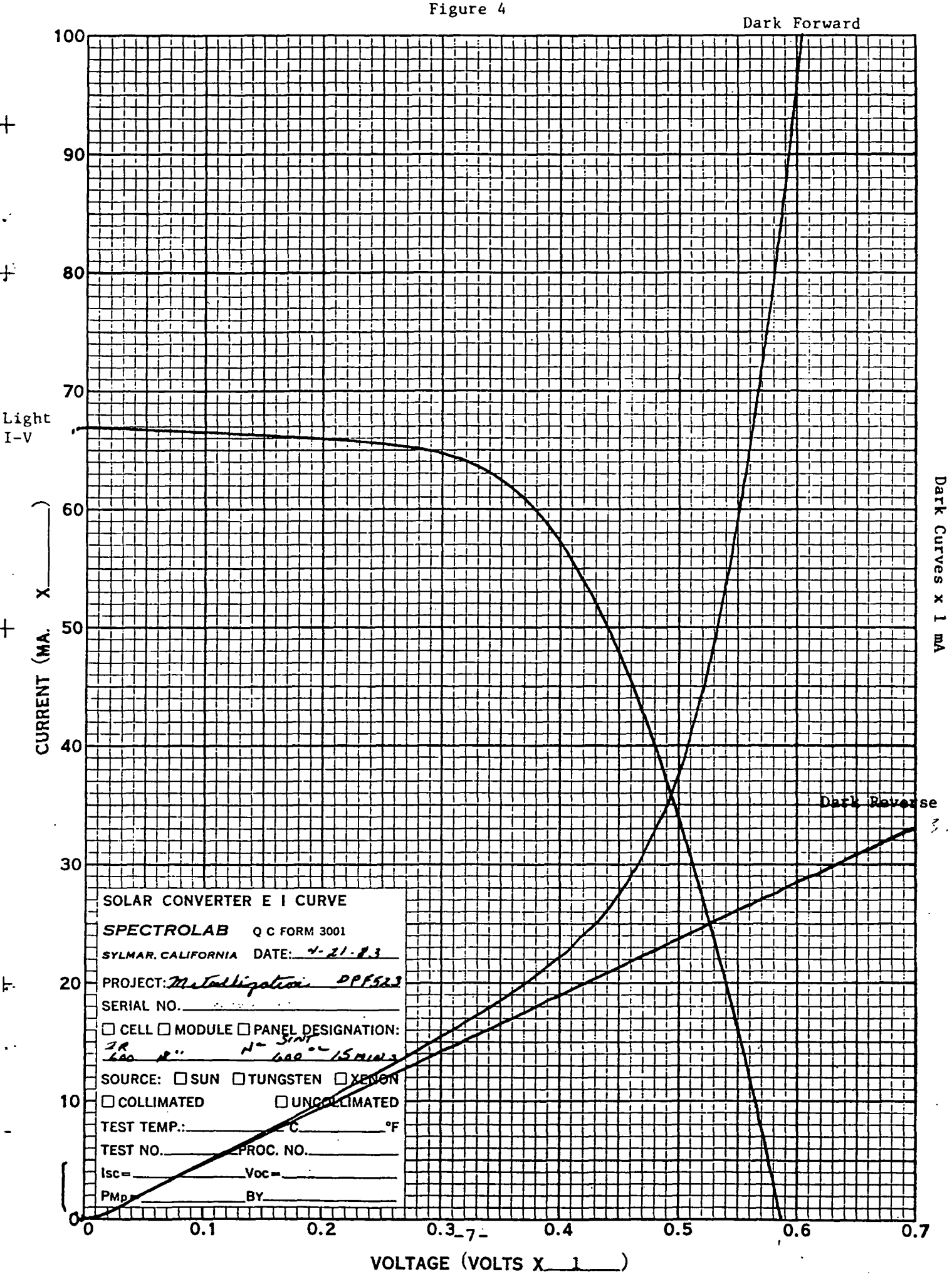
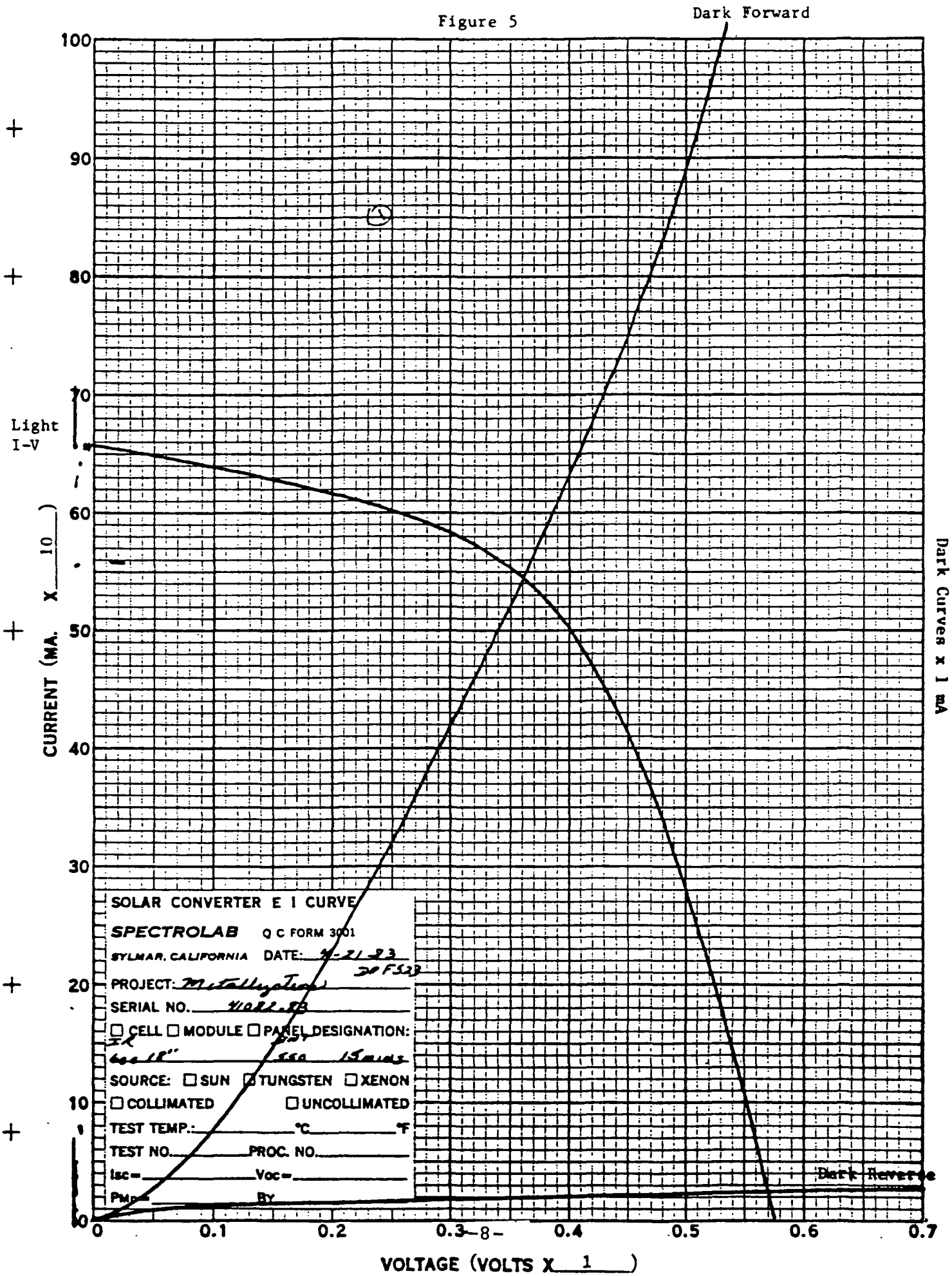

Dark Forward
Light I-V
Dark Reverse
Dark Curves x 1 mA
CURRENT (MA. X 1)
VOLTAGE (VOLTS X 1)
100
90
80
70
60
50
40
30
20
10
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
SOLAR CONVERTER E I CURVE
SPECTROLAB Q C FORM 3001
SYLMAR, CALIFORNIA DATE: 4-21-83
PROJECT: Metallization DPF523
SERIAL NO.
☐ CELL ☐ MODULE ☐ PANEL DESIGNATION:
SOURCE: ☐ SUN ☐ TUNGSTEN ☐ XENON
☐ COLLIMATED ☐ UNCOLLIMATED
TEST TEMP.: °C °F
TEST NO. PROC. NO.
Isc= Voc=
PMp= BY

Figure 5


Dark Forward
Light I-V
CURRENT (MA. X 10)
VOLTAGE (VOLTS X 1)
Dark Curves x 1 mA
Dark Reverse
100
90
80
70
60
50
40
30
20
10
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
SOLAR CONVERTER E I CURVE
SPECTROLAB Q C FORM 3001
SYLMAR, CALIFORNIA DATE:
PROJECT:
SERIAL NO.
☐ CELL ☐ MODULE ☐ PANEL DESIGNATION:
SOURCE: ☐ SUN ☐ TUNGSTEN ☐ XENON
☐ COLLIMATED ☐ UNCOLLIMATED
TEST TEMP.: °C °F
TEST NO. PROC. NO.
Isc= Voc=
PM= BY

fired in $H_2$ for 5 minutes at 600°C. The best cell had the following characteristics when tested by contacting the Mo/Sn metallization: $V_{oc}$ = .586, $I_{sc}$ = .650, $I_{500}$ = .448. When the cell was contacted on the Ag pad the $I_{sc}$ fell to .080. There is no ohmic contact between the two metallization types. Cells were also processed with 500 and 400°C prefire temperatures, but had similar characteristics. Interconnects were successfully soldered to the ohmic pad.

Another set of experiments was done using paste type F503 to which was added 3% Ag3347 silver paste. The cell was first printed with the Mo/Sn, prefired at 600°C, and fired in $H_2$ at 500°C for 5 minutes. The silver paste was printed and fired as before. The cell was tested and it was found to have an $I_{500}$ = .250, however there was ohmic continuity between the silver and Mo/Sn metallizations. The cell was then resintered several times for five minutes but continued to degrade. Figures 6 and 7 show typical cells. Sintering at higher temperatures destroyed the contact between the metallizations as is seen in Figure 8.

After meeting with JPL personnel a matrix of paste types was constructed to be manufactured by Electrink Inc. Two types of frits will be investigated, one with barium and strontium #494, and one without #90. Both frits are lead free. The formulations will also be prepared with and without Teflon powder. Two different vehicles will also be tested, a conventional cellulosic vehicle V-38 and an acrylic vehicle V-26. As controls pastes will also be prepared without frit and with lead borosilicate frit. The following table summarizes the pastes:

| Paste | Frit (Pb) | Frit 90 | Frit 494 | Teflon | V-26 | V-38 |
|---|---|---|---|---|---|---|
| A | | | X | | X | |
| B | | | X | X | X | |
| C | | X | | | X | |
| D | | X | | X | X | |
| E | | | X | | | X |
| F | | | X | X | | X |
| G | | X | | | | X |
| H | | X | | X | | X |
| I | X | | | | X | |
| J | X | | | | | X |
| K | | | | | X | |
| L | | | | | | X |

Figure 6

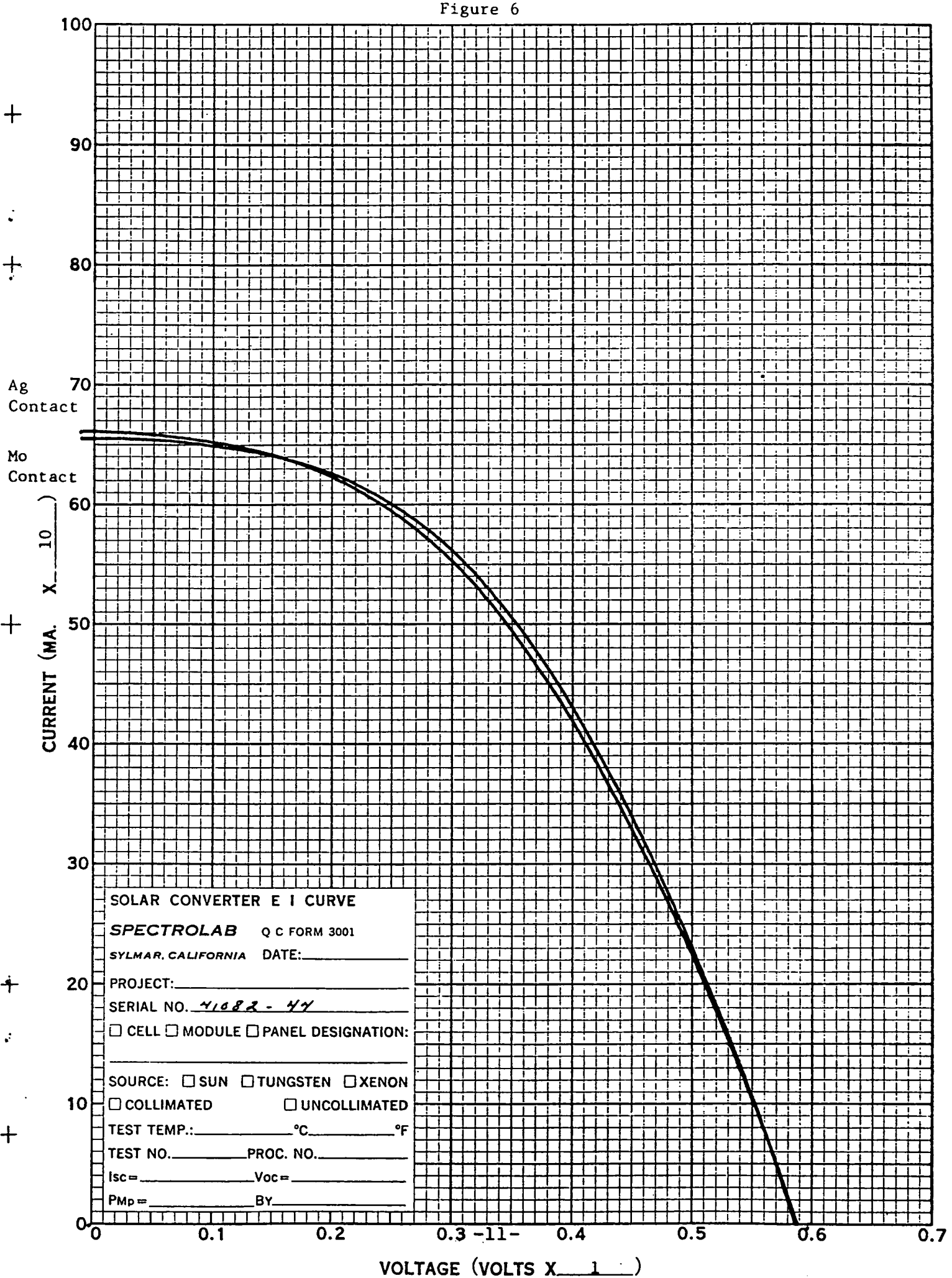

100
90
80
Ag
Contact
70
Mo
Contact
60
50
40
30
20
10
0
CURRENT (MA. X 10 )
0
0.1
0.2
0.3
-11-
0.4
0.5
0.6
0.7
VOLTAGE (VOLTS X 1 )
SOLAR CONVERTER E I CURVE
SPECTROLAB Q C FORM 3001
SYLMAR, CALIFORNIA DATE:
PROJECT:
SERIAL NO. 41082 - 44
☐ CELL ☐ MODULE ☐ PANEL DESIGNATION:
SOURCE: ☐ SUN ☐ TUNGSTEN ☐ XENON
☐ COLLIMATED ☐ UNCOLLIMATED
TEST TEMP.: °C °F
TEST NO. PROC. NO.
Isc = Voc =
PMp = BY

Figure 7

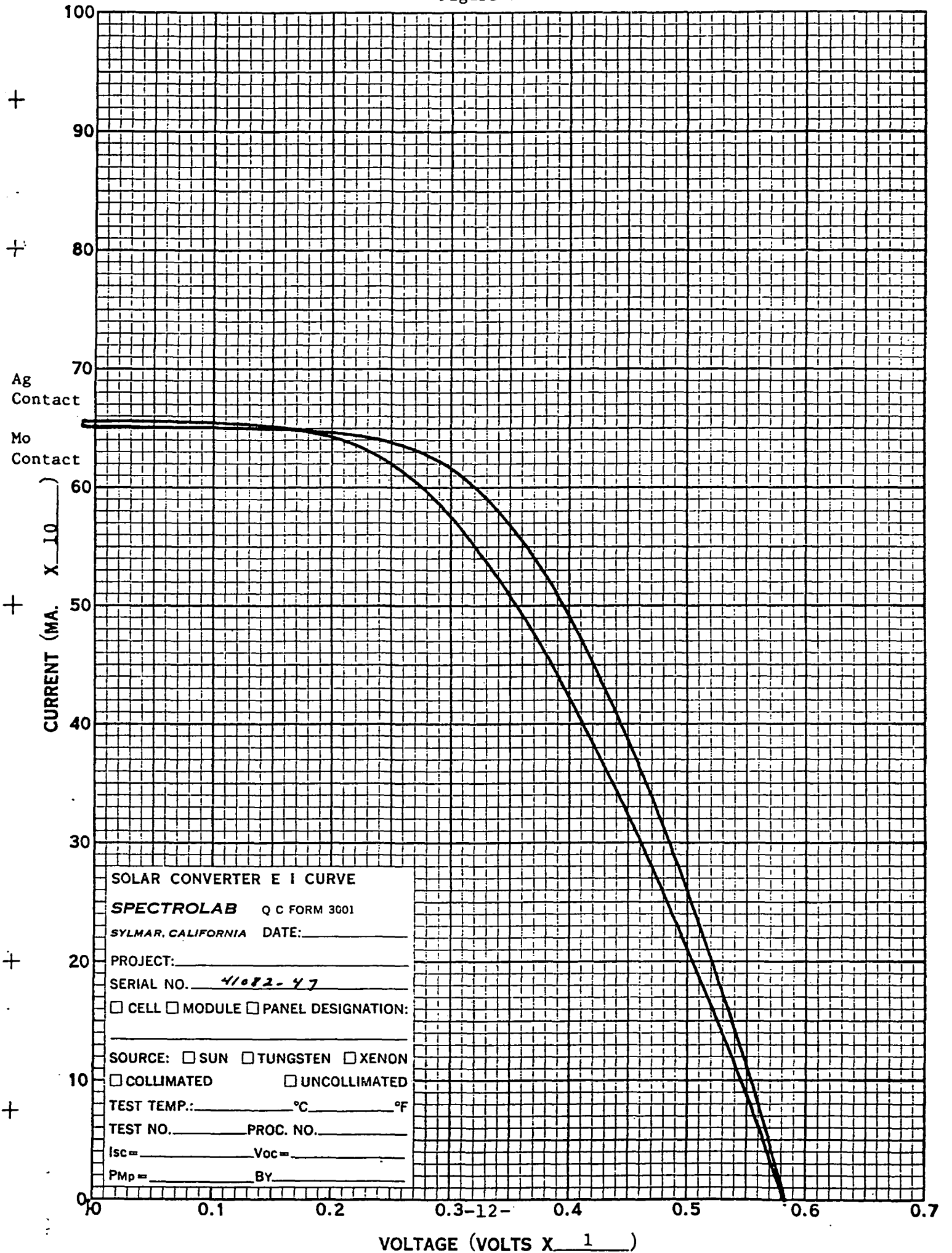
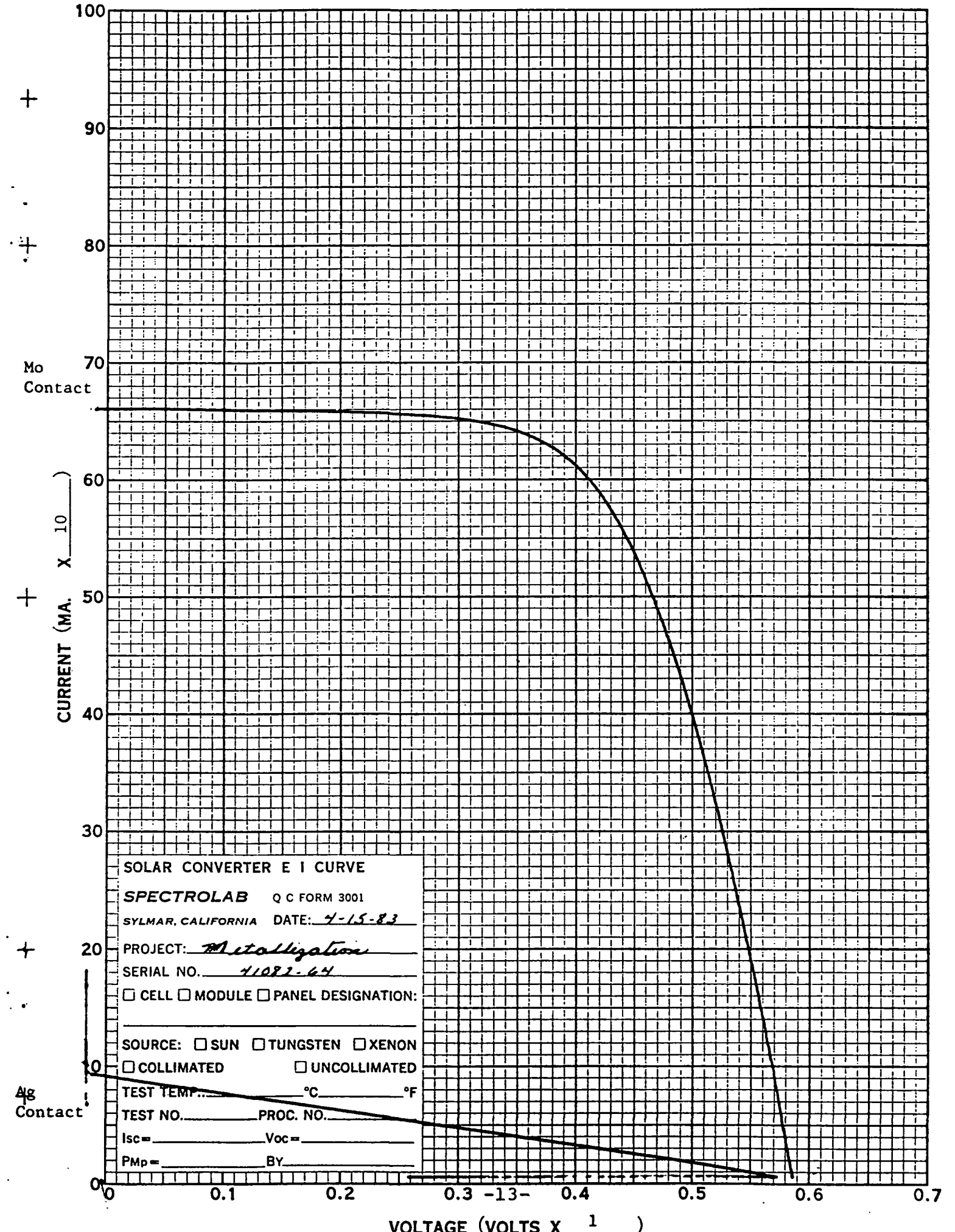

100
90
80
70
60
50
40
30
20
10
0
Ag Contact
Mo Contact
CURRENT (MA. X 10 )
0
0.1
0.2
0.3
-12-
0.4
0.5
0.6
0.7
VOLTAGE (VOLTS X 1 )
SOLAR CONVERTER E I CURVE
SPECTROLAB Q C FORM 3001
SYLMAR, CALIFORNIA DATE:
PROJECT:
SERIAL NO. 41082-47
☐ CELL ☐ MODULE ☐ PANEL DESIGNATION:
SOURCE: ☐ SUN ☐ TUNGSTEN ☐ XENON
☐ COLLIMATED ☐ UNCOLLIMATED
TEST TEMP.: °C °F
TEST NO. PROC. NO.
Isc = Voc =
Pmp = BY

Figure 8


100
90
80
70
60
50
40
30
20
10
0
Mo Contact
Ag Contact
CURRENT (MA. X 10 )
0
0.1
0.2
0.3
-13-
0.4
0.5
0.6
0.7
VOLTAGE (VOLTS X 1 )
SOLAR CONVERTER E I CURVE
SPECTROLAB Q C FORM 3001
SYLMAR, CALIFORNIA DATE: 4-15-83
PROJECT: Metallization
SERIAL NO. 41082-64
☐ CELL ☐ MODULE ☐ PANEL DESIGNATION:
SOURCE: ☐ SUN ☐ TUNGSTEN ☐ XENON
☐ COLLIMATED ☐ UNCOLLIMATED
TEST TEMP.: °C °F
TEST NO. PROC. NO.
Isc= Voc=
PMp= BY

## Section 3.0

## CONCLUSIONS AND RECOMMENDATIONS

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There are no conclusions or recommendations to report for the period.

## Section 4.0

## ACTIVITIES PROJECTION

During the next quarter the matrix of paste formulations will be evaluated. The work on ITO coatings over the metallization will not begin until a more successful process is found. A Milestone Chart follows.

SPECTROLAB
a subsidiary of Hughes Aircraft Co.

# MILESTONE CHART AND DELIVERY SCHEDULE

SHEET 1 OF 1
DATE 4/13/83
REVISION

| ITEM OR TASK | DESCRIPTION |
|---|---|
| 10 | FRONT METALLIZATION |
| 11 | Initial Formulation |
| 12 | Re-Formulations |
| 13 | ITO on Metal |
| 14 | Metal on ITO |
| 15 | Two Step Process |
| 20 | DEMONSTRATION RUN & EVALUATION |
| 30 | TESTING |
| 31 | Electrical Characteristics |
| 32 | Adhesion |
| 33 | Humidity |
| 34 | Contact Resistance |
| 40 | NON-CZ PROCESSES |
| 50 | MANAGEMENT |
| | Program Plan |
| | Monthly Technical Report |
| | Monthly Financial Report |
| | Quarterly Technical Report |
| | Process Specifications |
| | Economic Evaluation |
| | Prototype Cell Deliveries |
| | Final Report |

A M J J A S O N D J F M A M J J A S O N D

DRAFT

FINAL

LEGEND

NOTES

CUSTOMER JET PROPULSION LABORATORY

PROGRAM METALLIZATION

Q-