N85-32421

COMPREHENSIVE SILICON SOLAR-CELL COMPUTER MODELING

RESEARCH TRIANGLE INSTITUTE

M.F. Lamorte

Synopsis of Significant Progress

1. Model and analysis of the net charge distribution in quasineutral regions (investigation continuing in collaboration with Professor F A. Lindholm, University of Florida)
2. Experimentally determined temperature behavior of Spire Corp. n^+pp^+ solar cells where n^+-emitter is formed by ion implantation of ^{75}As or ^{31}P (Acknowledgments: M. B. Spitzer, Spire Corp.; and Ward J. Collis, North Carolina A&T State University, Greensboro, N.C.)
3. Initial validation results of computer simulation program using Spire Corp. n^+pp^+ cells.

Model and analysis of the net charge distribution in quasi-neutral regions: a model and a corresponding analysis has been developed that describes the net charge distribution which gives rise to built-in electric fields. Conclusions derived from analysis are:

a. only the redistribution of majority carriers, from their charge neutrality distribution, may affect the establishment of high-intensity built-in electric fields
b. charge neutrality exits in quasineutral regions only for position-independent and exponential doping concentration profiles
c. all other doping profiles produce a net charge concentration distribution
d. new mass action law is developed that applies to quasineutral regions in which charge neutrality is not present.

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Application to n+-region:

Electron concentration distribution:

$$n_n(x) = p_n(x) + N_D(x) - N_A(x) - \Delta N_n(x)$$

Net positive charge concentration:

$$\Delta n_n = \frac{E}{q}\,\frac{dE_n}{dx}$$

Mass action law:

$$p_n = \frac{N_D - N_A - \Delta n_n}{2}\left[\sqrt{1 + \left(\frac{2n_{ie}}{N_D - N_A - \Delta n_n}\right)^2} - 1\right]$$

for charge neutrality $\Delta n_n = 0$, and $p_n = \dfrac{n_{ie}^2}{N_D - N_A}$

Substitute p_n into n_n:

$$n_n = \frac{N_D - N_A - \Delta n_n}{2}\left[\sqrt{1 + \left(\frac{2n_{ie}}{N_D - N_A - \Delta n_n}\right)^2} + 1\right]$$

for charge neutrality $\Delta n_n = 0$, and $n_n = N_D - N_A + p_n$

Application to n+-region with Gaussian Donor Distribution:

Built-in electric field: $E_n = \zeta \dfrac{kT}{q}\,\dfrac{x}{2Dt}$

$$\zeta = \frac{1}{1 - \dfrac{N_A - \Delta n_n}{N_D}}$$

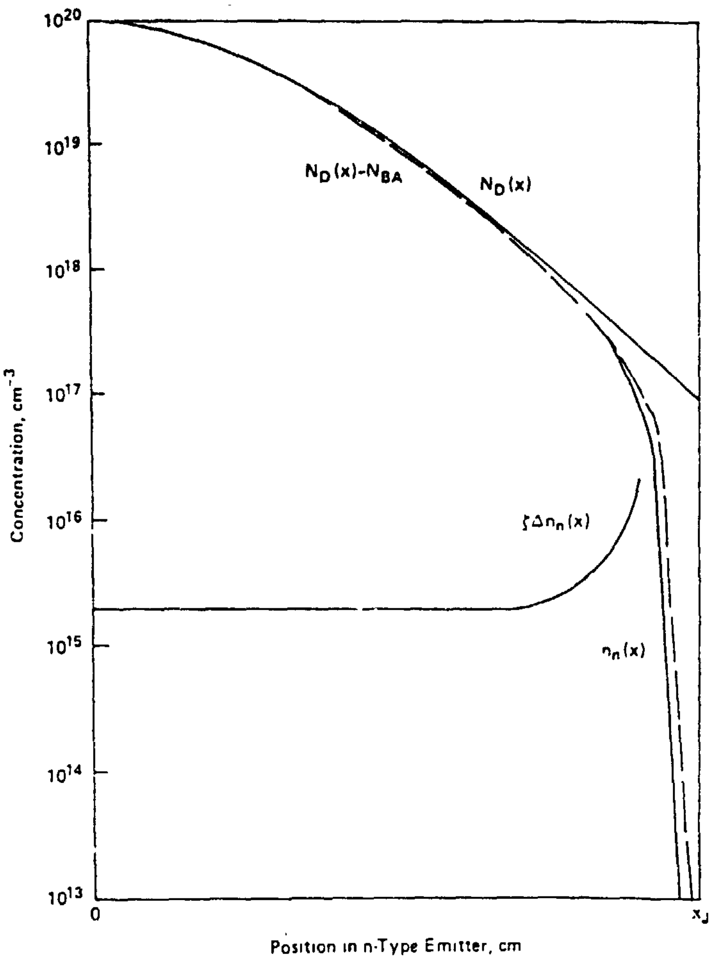
Far removed from the depletion region edge: $\zeta \quad 1$

$$E_n = \frac{kT}{q}\,\frac{x}{2Dt}$$

$$\frac{dE_n}{dx} = \frac{kT}{q}\,\frac{1}{2Dt} = \text{position independent}$$

$\Delta n_n \approx$ position independent (see Figure 1).

Figure 1. Representation of the Charge Distribution in the Quasi-Neutral n-Type Emitter Region of a Solar Cell that Establishes a Built-In Electric Field Attributed to a Gaussian Donor Concentration Profile.



Experimental Data Obtained from n^+pp^+ Spire Corp. Solar Cells at 28°C

Cell # 4408-	Ion (As/P)	Dose (Ions/cm^2)	L_D (μm)	QE (@ 350 μm)	VOL (mV)	JSC (mA/cm^2)	FF (%)	EFF (%)
1B	P	1×10^{14}	48	.18	541	20.1	77.1	8.39
4C	P	2×10^{14}	46	.31	577	20.7	77.9	9.28
6F	P	4×10^{14}	46	.44	603	20.5	79.4	9.81
8C	P	8×10^{14}	56	.43	608	21.0	80.1	10.2
10F	P	1×10^{15}	78	.42	610	21.7	81.0	10.7
12C	P	2.5×10^{15}	94	.37	610	22.4	80.3	11.0
14C	As	1×10^{14}	37	.31	559	20.1	71.3	8.03
16B	As	2×10^{14}	41	.42	590	20.6	77.0	9.37
17F	As	4×10^{14}	37	.44	603	20.6	77.5	9.61
20C	As	8×10^{14}	38	.47	605	20.6	79.5	9.91
22F	As	1×10^{15}	40	.46	603	20.8	80.7	10.1
24C	As	2.5×10^{15}	59	.44	595	22.8	74.1	10.1

Notes: cell area = 4 cm^2. T = 28°C. Insolation was AMI, 100 mW/cm^2. No AR coating.

Figure 2. Experimentally Determined Behavior of Efficiency versus Temperature Obtained from n^+pp^+ Spire Corp. Solar Cells Which Do Not Have AR Coatings.

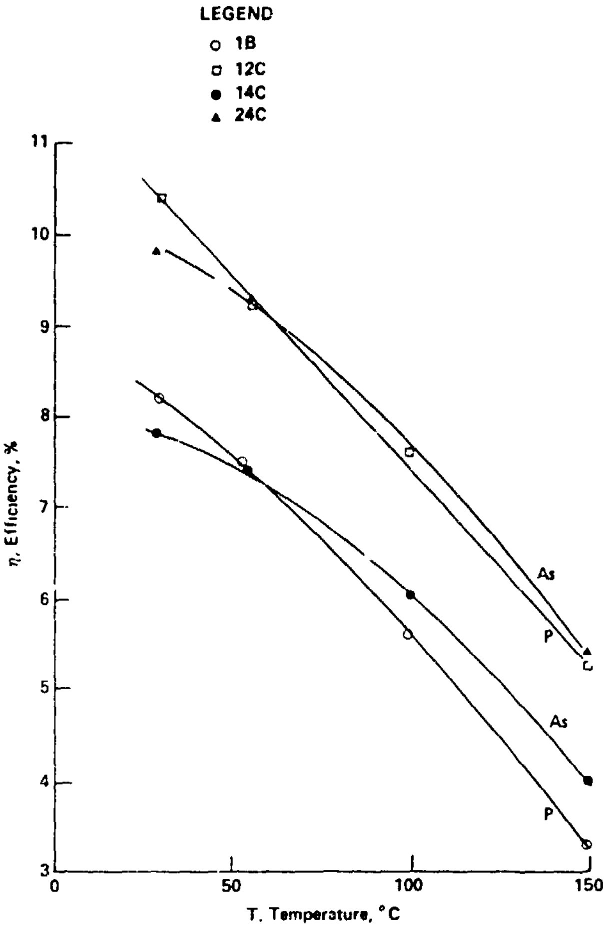


Figure 3. Experimentally Determined Behavior of Open-Circuit Voltage versus Temperature Obtained from n+pp+ Spire Corp. Solar Cells Which Do Not Have AR Coatings.

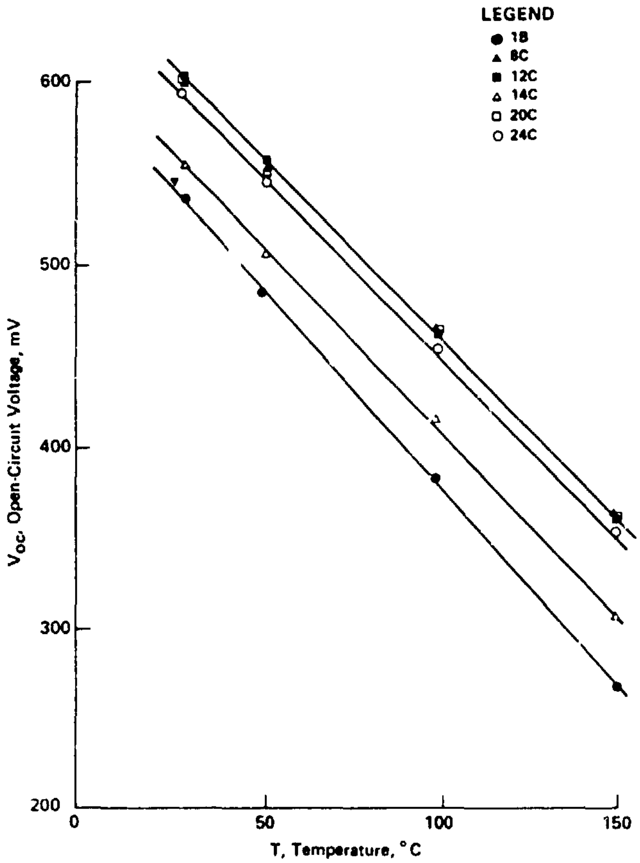
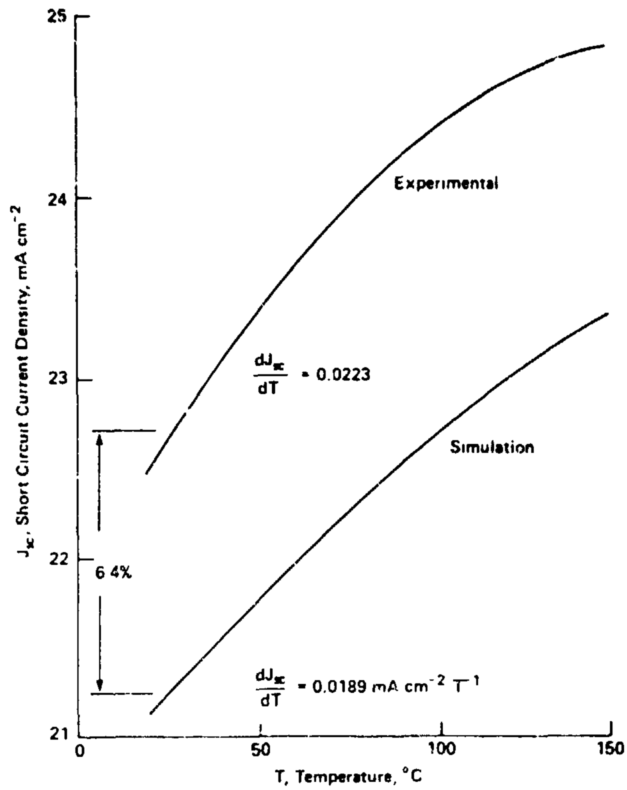


Figure 4. Comparison of Experimental Data and Simulation Results Describing the Behavior of the Short-Circuit Current Density Versus Temperatures for n^+pp^+ Spire Corp. Solar Cell No. 24C, Which Does Not Have an AR Coating.



Calculated Normalized Temperature Coefficients of Efficiency, Open-Circuit Voltage, and Short-Circuit Current Density Obtained from n^+pp^+ Spire Corp. Solar Cell Experimental Data Which Do Not Have AR Coatings

	Dose = 1×10^{14} cm^{-2}			Dose = 2.5×10^{15} cm^{-2}		
Figure of Merit*	^{31}P(1B)	^{75}As(14C)	Percent Change	^{31}P(12C)	^{75}As(24C)	Percent Change
$\frac{1}{\eta_o} \frac{\eta(150) - \eta_o}{\Delta T}$	-4.9×10^{-3}	-4.0×10^{-3}	+22.5%	-4.1×10^{-3}	-3.71×10^{-3}	+10.8%
$\frac{1}{(V_{oc})_o} \frac{V_{oc}(150) - (V_{oc})_o}{\Delta T}$	-4.1×10^{-3}	-3.7×10^{-3}	+10.8%	-3.4×10^{-3}	-3.4×10^{-3}	0
$\frac{1}{(J_{sc})_o} \frac{J_{sc}(150) - (J_{sc})_o}{\Delta T}$	0.9×10^{-3}	1.1×10^{-3}	−18.2%	$+0.63 \times 10^{-3}$	0.7[illegible] $\times 10^{-3}$	−17.1%
η_o (Spire Corp.)	8.39	8.03	4.5%	11.0	10.1	5.9%
η_o (NC A&T)	8.2	7.8	5.1%	10.4	9.8	6.1%

*No AR coating

Figure 5. Simulation of Electric Field Distribution in n⁺ of Spire Corp. Solar Cell No. 24C With Temperature a Parameter.

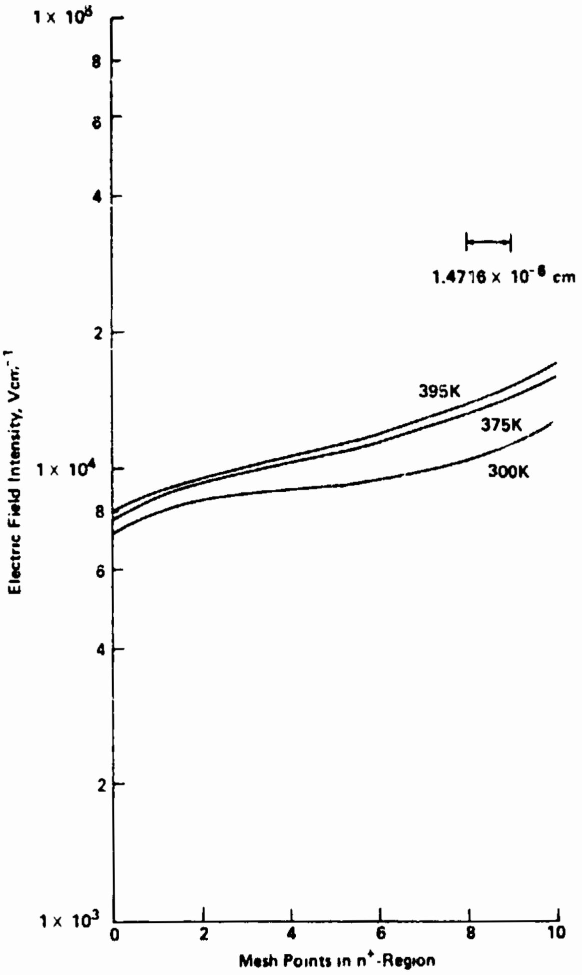


Figure 6. Net Charge Distribution in the n$^+$-Region of Spire Corp. Solar Cell No. 24C With Temperature a Parameter.

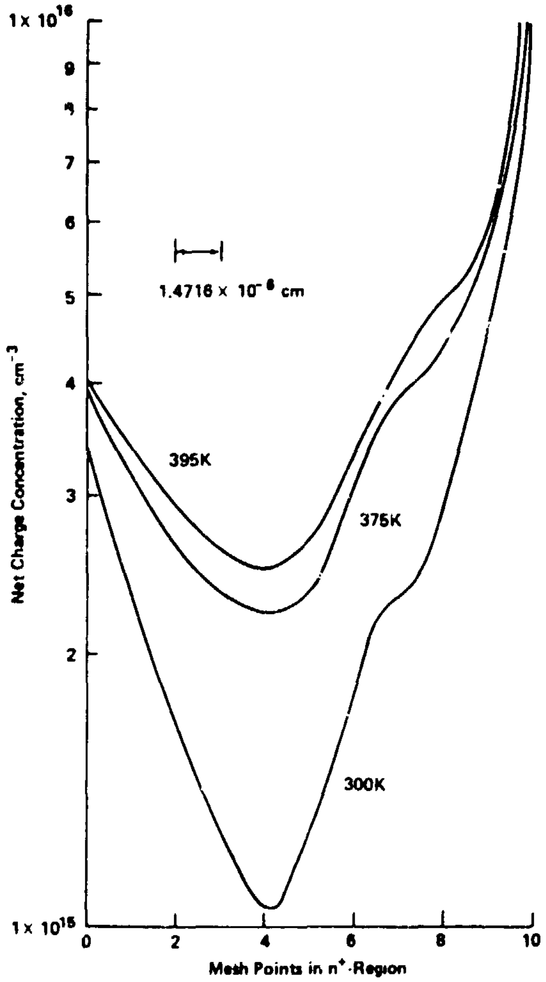


Figure 7. Simulation of Photoexcited Hole Concentration in the n^+-Region of Spire Corp. Solar Cell No. ?4C, With Temperature a Parameter.

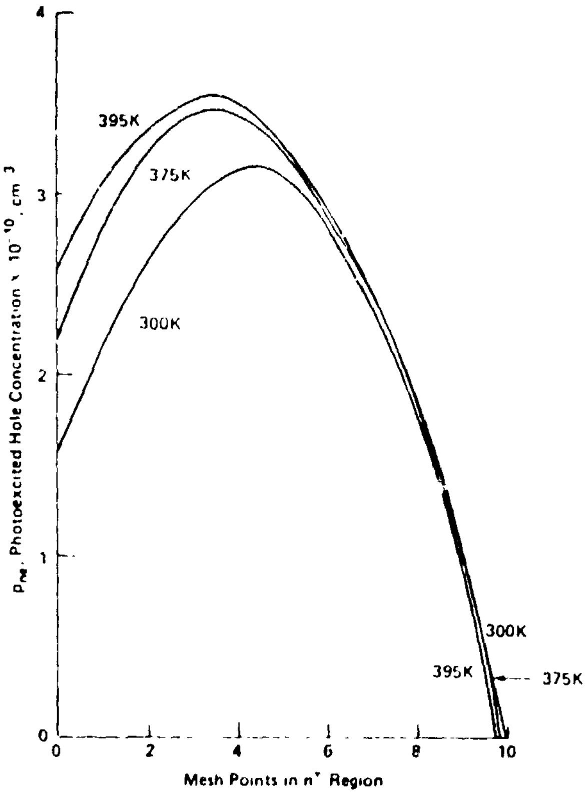


Figure 8. Lifetime and Transit Time Simulations of Holes in the n^+-Region of a n^+pp^+ Spire Corp. Solar Cell, No. 24C, Under Short-Circuit and 27° C.

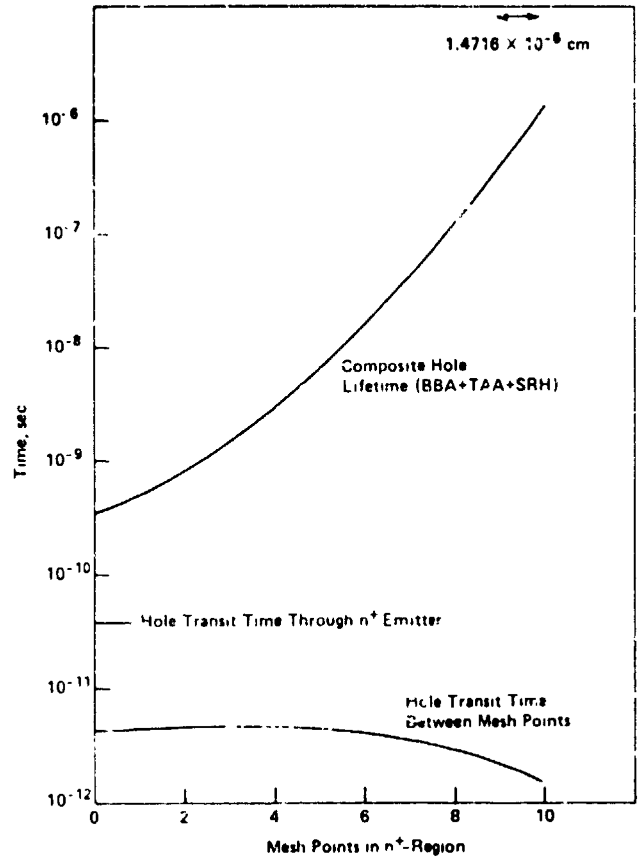


Figure 9. Short-Circuit Current Density versus Base Electron Diffusion Length Representing Spire Corp. n^+pp^+ Silicon Solar Cells and Computer Simulation Results of Cell No. 24C, no AR Coating, and 27° C.

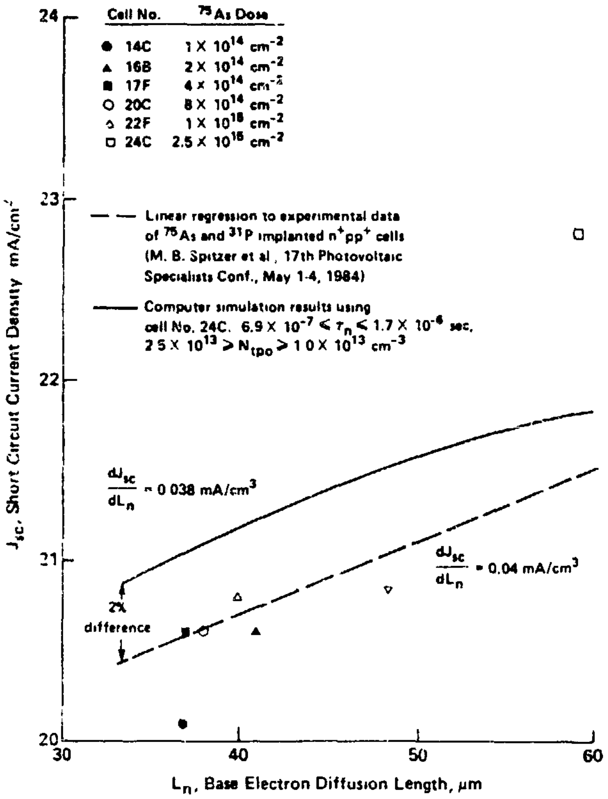


Figure 10. Behavior of Short-Circuit Current Density versus Base Electron Diffusion Length Obtained from Simulating Cell No. 24C, n^+pp^+, Provided by the Spire Corp., no AR Coating, and 27° C.