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AN ANALYSIS OF PHOTOCURRENT  
IN P-N JUNCTION SOLAR CELLS

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### บทคัดย่อ

ประสิทธิภาพของเซลล์แสงอาทิตย์สามารถพิจารณาได้จากพารามิเตอร์ใหญ่ ๆ ๓ ค่า คือ แรงดันวงจรมืด กระแสลัดวงจร และฟิลล์แฟกเตอร์ จุดประสงค์ของวิทยานิพนธ์นี้ก็เพื่อที่จะศึกษาผลของค่ากระแสไฟโตที่มีต่อสมรรถนะของเซลล์

การวิเคราะห์กระแสไฟโตสามารถทำได้โดยการคำนวณเชิงคณิตศาสตร์ ในแต่ละย่านของเซลล์แสงอาทิตย์แบบหัวต่อพี-เอ็นที่ทำด้วยซิลิกอน ได้แก่ ย่านพี ย่านเอ็นและย่านปลอดพาหะเพื่อคำนวณค่ากระแสไฟโตทั้งหมดของเซลล์โดยใช้หลักการซูเปอร์โพสิชันโดยการสมมุติว่า การเติมสารเจือปนค่าความคล่องตัวของพาหะและค่าเวลาของพาหะในย่านพีและเอ็นมีค่าสม่ำเสมอทั่วทั้งย่าน และที่บริเวณย่านปลอดพาหะมีค่าสนามไฟฟ้าสูงมากพอที่จะทำให้พาหะที่เกิดจากแสงถูกกวาดข้ามย่านนี้ไป โดยไม่มีการรวมตัวกัน การคำนวณนี้ทำได้โดยการเขียนโปรแกรมคอมพิวเตอร์ด้วยภาษาฟอร์แทรนสี่ เพื่อสร้างแบบจำลองผลและศึกษาคุณลักษณะแนวโน้มการเพิ่มค่ากระแสไฟโต

การเพิ่มค่ากระแสไฟโตสามารถทำได้โดยการแปรค่าพารามิเตอร์ต่าง ๆ ของเซลล์ เช่น ค่าระยะยลิกของหัวต่อ ค่าความต้านทานจำเพาะที่ฐาน จากผลการทดลองแสดงผลที่สอดคล้องกับการคำนวณ นอกจากนี้ผลการทดลองยังแสดงอีกว่าการกำจัดค่า dead layer และการทำเซลล์แสงอาทิตย์ชนิดที่มีสนามไฟฟ้าด้านหลัง (ปี เอส เอฟ) ทำให้ประสิทธิภาพของเซลล์สูงขึ้นกว่าเซลล์แสงอาทิตย์แบบหัวต่อพี-เอ็นธรรมดาเท่ากับ ๘ และ ๒๑ เปอร์เซ็นต์ตามลำดับ

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#### ABSTRACT

The efficiency of solar cells is determined by three main parameters, i.e. the open-circuit voltage,  $V_{OC}$ , the short circuit current,  $I_{SC}$  and the fill factor, F.F. The objective of this work is to study on the effect of photocurrent to the cell performance.

Numerical analysis of photocurrent was carried out in each regions of n-on-p junction silicon solar cells, i.e. p-region, n-region and space charge region. Total current produced in the solar cell was computed by the principle of superposition with the assumptions that both sides of the junction are uniformly doped and that the values of mobility and lifetime of minority carriers remain constant throughout each uniform region. It is also assumed that the electric field in the space charge region is high enough to accelerate the photogenerated carriers out of the region before they can recombine. A computer program in FORTRAN IV language is written to simulate the relevant model to study the increasing trend of photocurrent.

Increase of photocurrent in n-on-p silicon solar cells was achieved by varying some physical and geometrical parameters such as the junction depth,  $X_j$ , substrate resistivity,  $\rho$ , etc. The experimental results show

good agreement with the computation. Elimination of "dead layer" by anodic oxidation and the Back Surface Field effect are also experimentally investigated to study the increasing trends of the photocurrent. The results show that solar cells under the conditions of elimination of "dead layer" and of having the Back Surface Field effect have higher efficiency of 8 percent and of 21 percent than ordinary n-on-p silicon solar cells, respectively.

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DEDICATED TO

My mother, Mrs Ai-ngim Sirinaovakul  
and my father, the late Mr. Somsak Sirinaovakul



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## LIST OF SYMBOLS

$A$	cross-sectional area
$D_n$	diffusion coefficient of electron in p-type material
$D_p$	diffusion coefficient of holes in n-type material
$E$	electric field
$F(\lambda)$	incident photon density per second per unit band-width at wavelength $\lambda$
$FF$	fill factor
$G$	carrier generation rate due to incident light
$H$	total cell thickness (semiconductor regions only)
$I_m$	current at maximum power point
$I_s$	dark current preexponential term, reverse saturation current
$J_{sc}$	short circuit current density
$J_{dr}(\lambda)$	photocurrent density per unit bandwidth at wavelength, $\lambda$ due to collection from the depletion region
$J_p(\lambda)$	photocurrent density per unit bandwidth at wavelength, $\lambda$ due to hole collection from the n-side of the junction
$J_{ph}$	photocurrent density (same as short circuit current density for negligible series resistance)
$k$	Boltzmann constant
$L_n$	electron diffusion length in p-type material
$L_p$	hole diffusion length in n-type material
$N_a$	acceptor density
$N_d$	donor density
$N_t$	density of recombination centers
$n$	ideality factor in dark current of Schottky barrier

$n_i$	intrinsic carrier density
$n_p$	electron density in p-type material
$P_n$	hole density in n-type material
$P_{no}$	hole density at equilibrium in n-type material
$R$	reflectivity
$R_s$	series resistance
$R_{sh}$	shunt resistance
$S_p$	front surface recombination velocity (for holes)
$S_n$	back surface recombination velocity (for electron)
$T$	temperature in $^{\circ}K$
$V_d$	built-in voltage
$V_m$	voltage at maximum power point
$V_{oc}$	open circuit voltage
$V_{th}$	thermal velocity
$W$	depletion width
$W_{p+}$	width of the highly doped region at the back of a Back Surface Field cell
$x_j$	junction depth (width of the top region)
$\alpha$	absorption coefficient
$\sigma_p$	hole capture cross section
$\tau_p$	hole lifetime
$\tau_n$	electron lifetime
$\lambda$	wavelength
$\delta$	dead layer
$\psi_p$	low-high junction barrier height

## LIST OF DEFINITIONS

Air Mass	Secant of the sun's angle relative to the zenith, measured at sea level.
AM0	Solar spectrum in outer space.
AM1	Solar spectrum at earth's surface for optimum conditions at sea level, sun at zenith.
AM2	Solar spectrum at earth's surface for average weather conditions (technically, the spectrum received at earth's surface for 2 path traversals through the atmosphere).
Back Surface Field	A diffused or grown electrical contact to the base which blocks minority carriers but transmits majority carriers.
Base	The bulk region of the solar cell lying beneath the thin top region and the depletion region.
Dead Layer	A thin region adjacent to the front surface with very short lifetime. The dead layer is a result of the diffusion process, and extends over about a third of the top region.
Fill Factor	The fraction of the product of the short circuit current and open circuit voltage which is available as maximum power output.

Inherent Efficiency	The power conversion efficiency of a solar cell without accounting for series resistance, shunt resistance, or reflection losses.
Open Circuit Voltage	Light-created voltage output for infinite load resistance.
Photocurrent	The current generated by light.
Short Circuit Current	The current for zero-net bias voltage across the device. It can differ from the photocurrent if a large series resistance is present.
Top Region	The thin, heavily doped region of the cell adjacent to the surface (i.e., the P region in - a P/N cell or the N region in an N/P cell, etc.).