Fabrication of CdSe/Si Nanostructures Thin Films Heterojunction by DC Sputtering for Solar Cell Applications

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ARTICLE INFO	**ABSTRACT**
Keywords CdSe, Si wafer, Nanostructure, Plasma Sputtering	CdSe nanocrystalin thin films were deposited onto silicon wafer using DC plasma sputtering method. Quantification of the crystalline size of CdSe thin films has been achieved by X-ray diffraction (XRD) technique. Otical properties of prepared CdSe thin films including absorption coefficient and optical band gap, have been analyzed and evaluated in the wavelength range of 250-850 nm. In addition, the current-voltage characteristics of a CdSe/Si hetero-junction have been examined, and the results show that lighting causes an increase in photo-current. The open circuit voltage was 2.0 V and the short circuit current was 0.18 mA. The abbreviation open circuit current is Voc.

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1. Introduction

The development of new generations of highly efficient photovoltaic cells, such as GaAs, InP, AlGaAs/GaAs, Si, CdSe/Ge, and others, is of critical relevance for future space power applications. n-CdSe/p-Si heterojunction solar cells provide various advantages over conventional Si-homojunction solar cells, including easier fabrication.. Heterojunction solar cells n-CdSe/p-Si provide several benefits over traditional Si-homojunction solar cells including easier manufacture. CdSe is a direct band gapsemi-conductor with interesting spintronics, electronic and opto-electronic features [1 Furthermore, low-temperature techniques (chemical spray or evaporation sputtering) can be used for preparing an n-CdSe/p-Si structure, limiting lifespan degradation and making it appropriate as an inexpensive space solar cells. In the hetero-junction solar cells, low resistivity of CdSe films are necessary in order to reduce the cell series resistance, restrict bending in narrow band gap materials, and reduce conduction band-Fermi level energy gap [2,3]. In addition, the semiconducting material CdSe has been utilized in heterojunction fabrications due to its photosensitive and nanocrystalline features. Through a layer of CdSe (bandgap = 1.74eV), sunlight is allowed to pass. In this type of device, CdSe is known to as the window layer. CdSe has an almost perfect band gap for the solar spectrum [4]. thus, n- Thin film solar cells based on n-CdSe/p-Si have been regarded as attractive alternatives for solar cells with high efficiency and cheap cost. On the other hand, in order to decrease manufacturing costs and user hesitancy due to cadmium toxicity, it is necessary to achieve an effective level of high energy conversions by applying a photovoltaic active layer with reduced thickness. [5, 6]. Many other transparent n-type semiconductor films like CdSe and CdS, can be deposited onto p-type semiconductors such as Si wafers to create PVs heterojunction[7& 8]. CdS has been successfully envisaged as a window layer material in various heterojunction solar cells. Using CdSe as absorbers, one can create effective and efficient heterojunction solar cells [9,10]. In this study, an n-CdSe/p-Si solar cell has been created via plasma sputtering of CdSe onto a p-Si wafer. Electrical properties as well as optical characteristics of fabricated heterojunction solar cells has been studied.

2. Experimental Details

CdSe thin film deposited on silicon (Si) wafer by DC plasma sputtering method. CdSe thin films were deposited on substrates of silicon (Si) wafers with a resistivity of 2.1 Ω.cm and the dimension of 1x1 cm. The Si wafers have been etched using the CP-4 etching solution for 2min, CP-4 etching solution has been made through the addition of 20mL of the hydrofluoric acid to 30mL of acetic acid and 60mL of HNO_3. Following the etching, Siwafers were washed for 5min. by distilled water followed by the ethyl alcohol. The CdSe was used as a target material and the dimeter disk was 50 mm. Substrates were introduced subsequently into chamber. Prior to thin film deposition, the target has been presputtered in atmosphere of Argon for approximately 15min so that any layer of the oxide stays on target surface may be removed. The chamber has been evacuated to $5x10^{-6}$mbar pressure before introducing pure Argon (99.99%) gas. and the working gas pressure was $5x10^{-2}$mbar. D.C. power supply was turned on. D.C. with power of 100W. The side of the CdSe thin film has been overcoated by indium mesh to be utilized the grid electrode. Following CdSe: In film Coated, ohmic rear contact has been produced by the Al electrodes' vacuum evaporation. After that, the front electrode has been made by the evaporation of Al metal grid via metal shadow mask. Ultimately, n-CdSe/p-Si heterojunction was annealed for 4hr at a temperature of 300^oC for the completion the formation of the junction. Measurement of the solar cell C-V properties of a solar cell has been performed with illumination from a 100 mW/ cm^2 tungsten lamp. Power and a voltage were applied to the sample by a dc power source in the range of (-1 to 2) V. Digital electrometers were used to measure the current flowing through the cell.

3. Results and Discussion

3.1 X-Ray Diffraction Studies

Figure1 illustrates the XRD of the prepared CdSe thin film.. The XRD peak is appeared at diffraction angle 2θ of 25.457^o which corresponding to (002) crystalline plane of hexagonal wurtzite CdSe structure.. 2. Further, other low intensity of XRD peaks is appeared at 2θ of 46.0811^o that related to (103) crystalline plane in agreement with standard database [9-11].

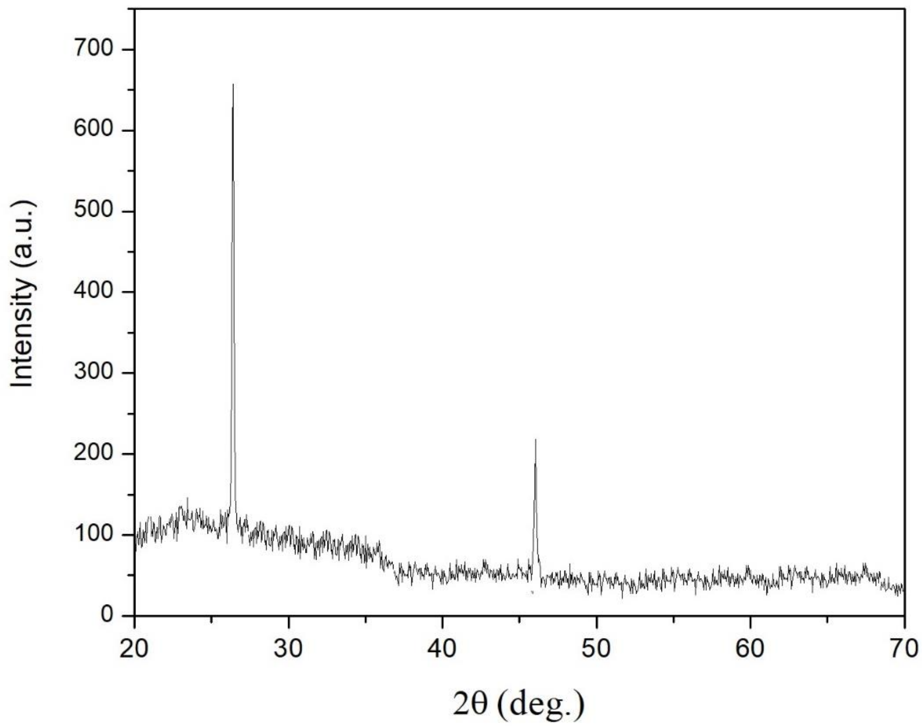

Figure 1: XRD of prepared CdSe thin film

The crystallite size of the (D) could be calculated using Scherrer's equation from full width at half maxima (FWHM) [11]:

$D = 0.94\, \lambda / \beta \cos\theta$ …………………………..(1)

In which λ represent wave-length of used X-ray, θ Bragg angle between incident and scattered X-rays.

The next relation is used to evaluate the strain values ε,

$\varepsilon = \beta\cos\theta/4$ …………………………………….(2)

Bragg's formula was used to calculate the lattice spacing 'd',

$d = \lambda/2 \sin\theta$……………………………………..(3)

Lattice parameters 'a' and 'c' have been specified for the hexagonal structure via the next equation:

$1 / d^2 = 4/3 \{h^2 + hk + k^2) / a^2\} + (l^2 / c^2)$……………………………….(4)

The lattice planes have been represented by h, k, and l. Table 1 shows the results of calculating the crystallite size of thin film of CdSe. The XRD pattern's sharp and intense peaks demonstrate the films' good crystallinity and prove the stoichiometric nature regarding the CdSe films [11]. The structural parameter were 45 nm, 25.447° and 3.497 Å of the size of the crystallite, 2 θ, and d-spacing Experimental respectively.

3.2 Optical properties

Figure 2 shows the absorbance spectra of CdSe thin films were deposited onto glass substrates at room temperature in spectral range of 250–850 nm. The relation used to compute the optical band gap 'Eg' [12-14]:

$$\alpha = A\,(h\nu - Eg)^{n}/h\nu \qquad (5)$$

Where A constant value and n has been equal to 1/2 for the direct band gap semi-conductors. Also, plots of $(\alpha h\nu)^2$ vs. hν have been displayed in Figure 3 for the CdSe thin film. In addition, optical band gap E_g, is identified as x-axis. The value of E_g was 1.75 eV. The coefficient of the extinction k was estimated with the use of well-known formula [15],

$$\alpha = 4\pi k/\lambda \qquad (6)$$

Where λ represent the incident beam's wavelength. Regarding such films, the absorption coefficients have been high (approximately $10^4 cm^{-1}$). In addition, values related to coefficient of absorption (α), energy band gap (E_g) and coefficient of extinction (k) therefor were provided in Table 2. The absorption coefficient calculated using this formula: α = 2.303x A/d, where d is thickness, A is absorption and α is the absorption coefficient, respectively. The optical parameters of the CdSe thin film were calculated of absorption coefficient (α),extinction coefficient (k) and optical band gap(Eg), 4.6×10^4 cm^{-1}, 0.224 and 1.75 eV respectively.

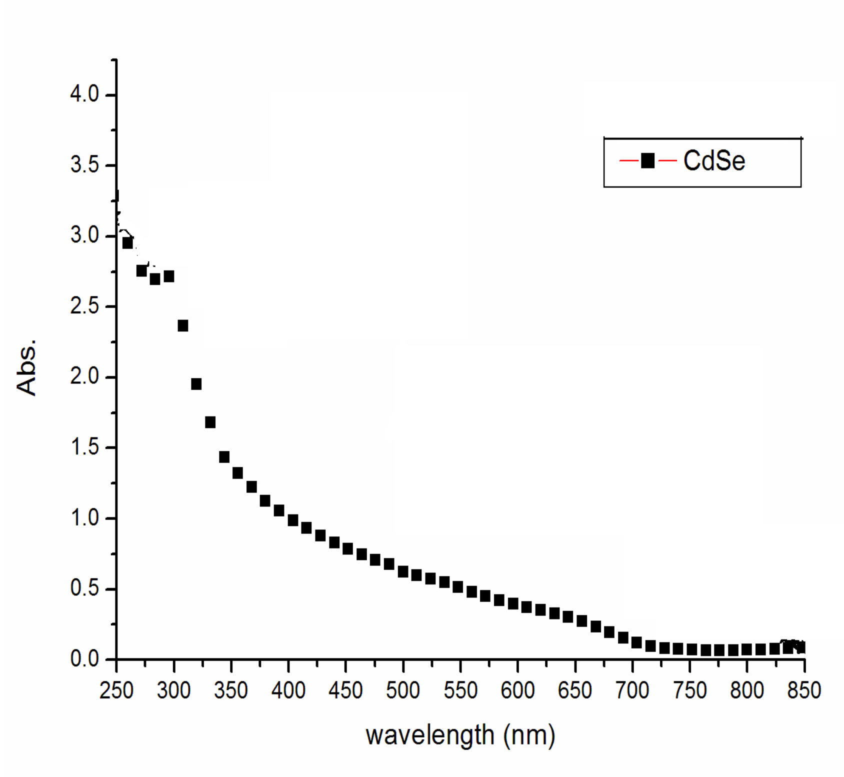

Figure 2: Absorption spectrum vs. wavelength (λ) of preparedCdSe thin films.

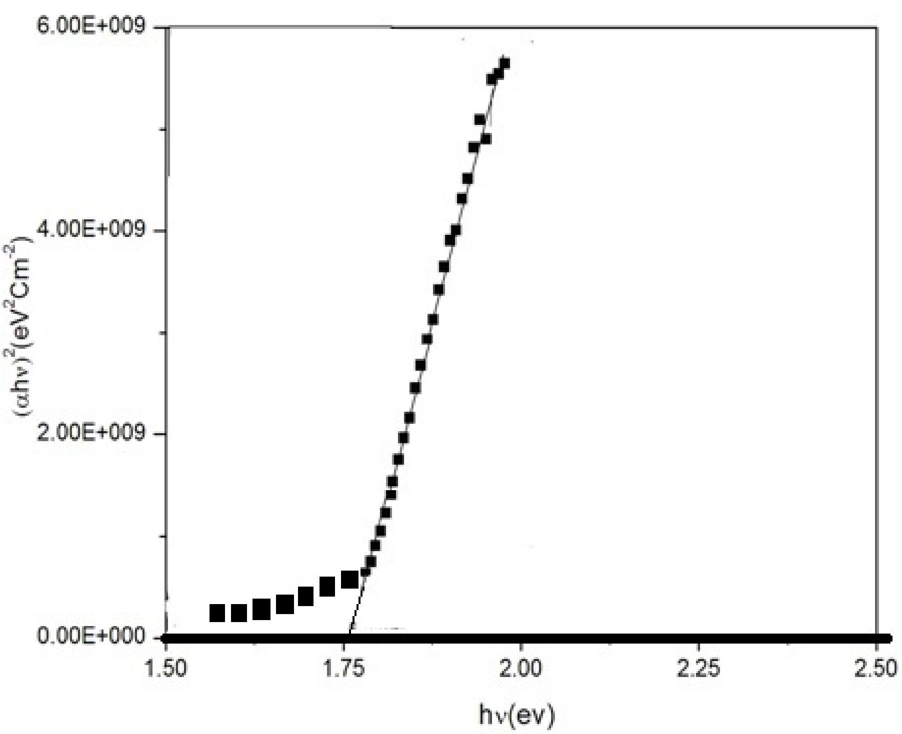

Figure 3: Plots of (αhν) 2 versus hν for CdSe thin films.

3.3 Hall Effect

The Hall Effect is used to determine the kind of majority charge carriers, Hall mobility (μH), and concentration in CdSe thin films deposited at room temperature (nH). The Hall effect was next explored, and the Hall coefficient was derived with the use of an equation [16].

$R_H = V_H x t / I x B$……………………………………(7)

Where t is the film thickness (1500 Å), and B represent the magnetic field (0.257 x 10^{-4} Tesla). According to equation (7) and Figure 4, the (-ve) sign of the Hall Coefficient (R_H) indicates that the carriers are electrons and semi-conductor is n-type. The coefficient of Hall (R_H) was (- 6.5*10^2 m^2/c) this result is confirming that the CdSe is n-type. Carrier mobility is typically defined as μ ≡ ν/E = σ/en, where ν is the Drude carrier drift velocity and it was3.6*10^2 cm^2/V.Sec, E is applied electrical field, assumed to be small, σ is conductivity, n is carrier density was 2.98* 10^{13} cm^{-3}.

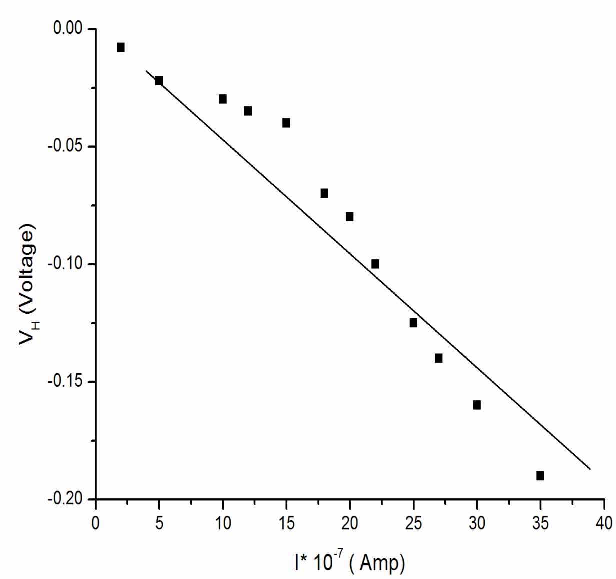

Figure 4: The plot of V_H against I for n-type semiconductor for CdSe thin film.

3.4 C-V and I-V measurements

Figure 5 shows inverse square relationship of capacitance versus the reverse bias voltage for the n- CdSe/ p- Si hetero-junctions at a 1MHz fixed frequency. The built-in potential is represented by the intersection of straight line with voltage axis at ($1/C^2 = 0$), and a slope of ($1/C^2$) versus V represents the concentration of the carrier [17].

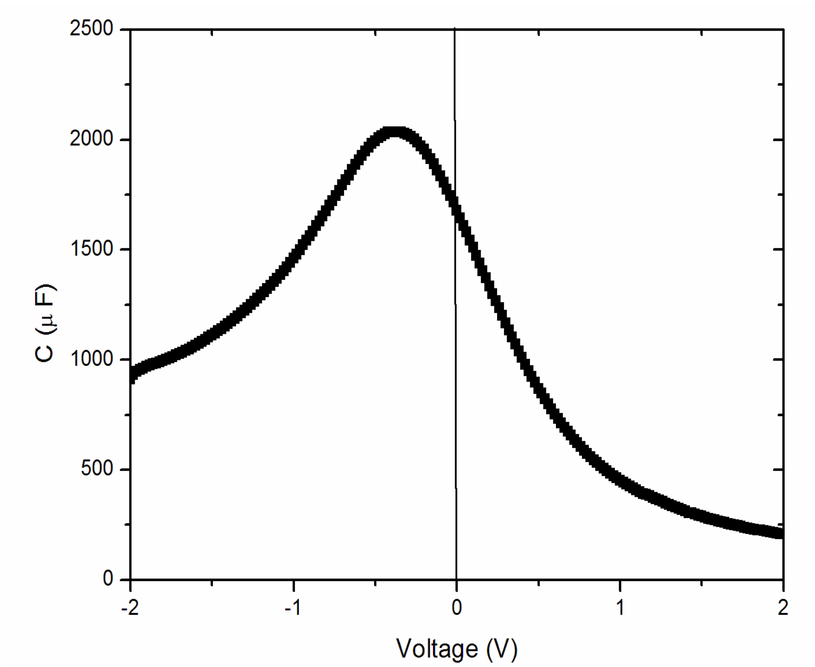

Figure 5: C- V characteristics of CdSe/ Si thin film.

The electrical characteristics of the solar cell was investigated in the dark and light illumination with intensity of 30 mW/cm^2. The solar cell parameters, short circuit current density (Isc), open circuit voltage (Voc), and maximum out putted power (Pm) were determined. During dark I-V measurements, a light-proof cover shields the cell under test. The dark I-V curve is measured in forward and reverse directions as shown in Fig. 6. This device's current value at a given voltage is higher in light compared to the dark. As a result of the generation of excitons as well as their subsequent dissociation to free charge carriers at barrier interface, light absorption through active layer CdSe/Si creates carriers that provide photocurrent. Free electrons and holes have been propelled toward electrodes over a potential barrier at interface, as it has been measured through illumination, under effects of electric field at junction. Internal defects will be reduced as crystal quality regarding CdSe nanoparticles improves, which will decrease photoexcited carrier recombination and lead to greater power conversion efficiency. [14].

fill factor and efficiency have been calculated using the equation [19],

F.F.= I_{max} V_{max} / I_{sc} V_{oc}……………………………(8)

η= ($I_{sc}V_{oc}$ F.F. / $P_{in)}$ x 100% ………………………(9)

Isc represents current of short circuit, V_{oc} represents open-circuit voltage, FF represents fill factor, P_{in} represents power density of incident light, η represents the efficiency of the power conversion, V_{max} and I_{max} represent current and voltage at maximal power point. Table1 was listed the evaluated of the I–V parameters (I_{sc}, V_{oc}, $I_{max,}$ V_{max}, $P_{max,}$ FF, and η) were taken from Fig. 6. The efficiency of as prepared solar cell have been measured. The efficiency of the device is low as a result of a loss of carriers because of the re-combination within CdSe layer. This may be because surface states that are present in nano-structured CdSe film which is evident through photoluminescence spectrum. Saha et al, have reported that the synthesized of CdS/ p-Si nanoparticles for photovoltaic cell by a simple chemical method, the efficiency of CdS/ p-Si was very low due to presence of surface traps in nano CdS. [19]. Shaikh et al, have reported that the fabrication of n-CdSe/p-Cu_2Se Heterojunction Solar Cells And found the efficiency of the power conversion is 0.67% which needs to be improved either by engineering interfacial layer or on doping fast charge transport materials that endow smaller charge transfer resistance [7].

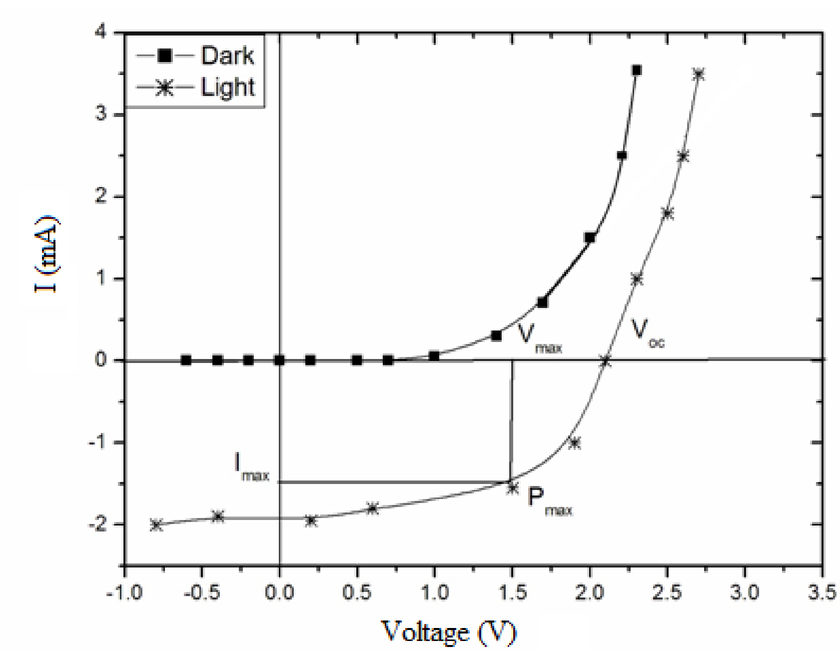

Figure 6: I-V characteristics for CdSe/ Si thin film under dark and illumination.

Table 1: Obtained of fabricated solar cell parameters.

I_{sc} (mA)	0.18
V_{oc} (V)	2
I_{max} (mA)	1.5
V_{max} (V)	1.5
FF	6.25
η %	2.25
P_{max} (mWalt)	100

Conclusions

CdSe thin film was deposited on a Si wafer utilizing a DC sputtering technique with a single target. Optical and structural properties of deposited CdSe thin film has been measured. It was discovered that the film is polycrystalline and has a straight band gap of 1.75 eV for CdSe thin film. Thin film CdSe/Si cells' I-V, optical characteristics, and junction capacitance have been investigated, indicating that CdSe is n-type. When a strong forward bias is applied across the cell, these features have numerous critical properties, including the inversion of the polarity of the short-circuit current. Thin film heterojunctions are often characterized by a drift in the I-V voltage characteristic, a cross-over effect, and an increase in loss current upon illumination. According to I-V characteristics, the cell's efficiency was 2.25%.

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تحضير أغشية البنية النانوية CdSe على السيليكون بواسطة رش البلازما للتطبيقات على الخلايا الشمسية

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المستخلص

قمنا بتحضير غشاء رقيق من مادة CdSe وتم ترسيبه على شرائح من السيليكون باستخدام طريقة الترذيذ بالبلازما من أجل لحصول على CdSe ذو حبيبات نانوية لاستخدامه في دراسات الخلايا الشمسية. تم استخدام حيود الأشعة السينية (XRD) لتحديد الحجم البلوري لأغشية الرقيقة CdSe . تم تقييم الخصائص البصرية (معامل الامتصاص وفجوة النطاق البصري) للغشاء الرقيق CdSeفي النطاق الطيفي 250-850 نانومتر. بالإضافة إلى ذلك ، تم اختبار خصائص الجهد الحالي لتقاطع CdSe / Si غير المتجانس ، وقد لوحظت زيادة في التيار الضوئي مع الإضاءة. كان تيار الدائرة القصيرة 0.18 (Isc) مللي أمبير وكان جهد الدائرة المفتوحة 2.0 (Voc) فولت.