Textured ZnO improves III-V on germanium solar cell performance

Reduced reflection boosts conversion efficiency from 24% to 29.8%.

National Formosa University in Taiwan has developed a liquid-phase deposition (LPD) process of textured zinc oxide on III-V semiconductor to provide improved absorption of multi-junction solar cells [Po-Hsun Lei et al, J. Phys. D: Appl. Phys., vol46, p125105, 2013].

The textured layer reduces reflection of the incident light over a broad band of wavelengths (300–1000nm). Traditional anti-reflective coatings tend to be wavelength selective. The researchers were seeking a low-cost process to produce randomly textured surfaces as a means to improve solar cell light absorption performance.

The gallium indium phosphide/indium gallium arsenide/germanium (GaInP/InGaAs/Ge) solar cell material formation process consisted of MOCVD on germanium for the active material and a liquid-phase deposition in a Teflon vessel in a controlled-temperature water bath for the textured zinc oxide layer (Figures 1 and 2).

The epitaxial material was cut up into 5mm x 5mm square chips. The ohmic p-contact was made to the back of the Ge substrate with a gold/zinc/silver/gold alloy. The ohmic n-electrode structure consisted of germanium-gold/nickel/gold on the n-InGaAs top layer. A ridge n-contact was made by partially exposing regions of n-type aluminium indium phosphide (n-AlInP) window layer underneath by etching into the n-InGaAs.

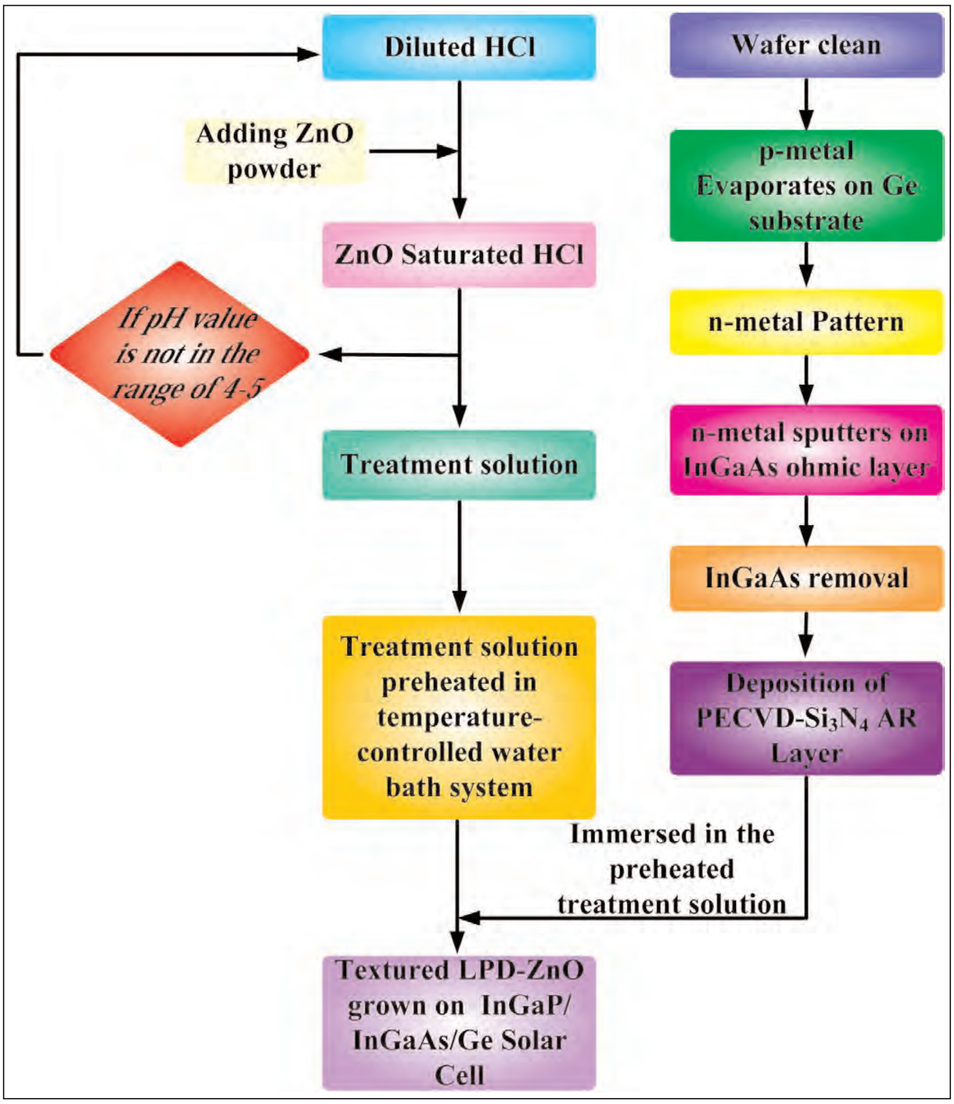

Figure 1. Flow chart for the LPD-ZnO process (left side) and fabrication of GaInP/(In)GaAs/Ge solar cells (right side).

A silicon nitride (Si3N4) anti-reflective coating was applied to the n-AlInP using plasma-enhanced chemical vapor deposition (PECVD). The n-InGaAs is used for the electrical contact, but absorbs wavelengths that should be converted by the GaInP layer.

The ZnO was deposited on the silicon nitride. The researchers carried out a number of experiments to optimize the process parameters (pH, temperature) for control of layer thickness and root-mean-square (RMS) roughness. The textured ZnO layer consisted of nests of hexagonal flakes (Figure 3).

The aim of the ZnO layer was to reduce the reflection of light away from the solar cell. The optimum growth conditions for this were found to be 25°C with 6 mole/liter (M) hydrochloric acid solution. Also, the researchers performed simulations suggesting that the maximum

n-contact/window	n-InGaAs/n-AlInP
Sub cell	GaInP
Tunnel junction	p-AlGaAs/n-GaInP
Sub cell	InGaAs
Tunnel junction	n-GaAs/p-GaAs
Substrate	p-Ge

Figure 2. MOCVD heterostructure.

Table 1. Performance of GaInP/(In)GaAs/Ge solar cells with textured LPD-ZnO window layer grown at 25°C in 6M HCl solution.

Run	SC current (mA/cm^2)	OC voltage (V)	Conversion efficiency (%)	Fill factor
1	14.25	2.43	29.71	0.85
2	14.35	2.43	29.65	0.84
3	15.09	2.41	29.64	0.81
4	14.92	2.34	28.43	0.81
5	14.57	2.42	29.78	0.84
6	15.00	2.42	29.79	0.82
7	14.85	2.41	29.81	0.83
8	14.81	2.41	28.92	0.811
9	14.73	2.39	29.50	0.83
10	14.73	2.39	29.63	0.84
11	14.81	2.39	29.81	0.84
12	14.72	2.38	29.80	0.85

enhancement for solar cells designed for a broad wavelength range would come from 95nm RMS roughness.

A bare solar cell without ZnO had a short-circuit current density of 12.5mA/cm^2 and energy conversion of 24%. This is similar to the performance achieved by others, according to the researchers. With ZnO deposited from 6M solution at 25°C, these were increased to 14.22mA/cm^2 and 29.8%, respectively.

Over a series of runs (Table 1), ZnO deposited from 6M solution at 25°C showed small variations in the character of the ZnO layer and in the performance of the solar cells. The RMS roughness of the ZnO layer varied in the range 90–100nm, while the pH value of the growth solution was kept in the range 4–5.

The researchers comment: "The uniformity of the RMS roughness is extremely significant because this is the primary factor determining the absorbed light intensity or scattering between air and the textured LPD-ZnO."

The variation in performance values were 3.31% for short-circuit current, 0.87% for open-circuit voltage, 3.75% for conversion efficiency, and 2.51% for fill factor.

The solar cells were also tested at operating temperatures up to 100°C. The variation in open-circuit voltage was 5.8mV/°C for cells without textured ZnO and 5.9mV/°C with. The respective rates for short-circuit current density were 7.9 and 8.0μA/°C-cm^2. The performance of solar cells tends to show that degraded energy conversion at high temperature and an increase in thermal resistance from added layers can be a concern for thermal management. The negligible changes in performance at raised temperature suggest that the ZnO layer does not significantly trap heat.

The researchers comment: "The introduction of the textured LPD-ZnO window layer for GaInP/(In)GaAs/Ge solar cells shows similar temperature characteristics as compared with those without the textured LPD-ZnO window layer. This may be attributed to the porosity of LPD-ZnO, which offers a path for reducing the thermal energy." ■

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Author: Mike Cooke

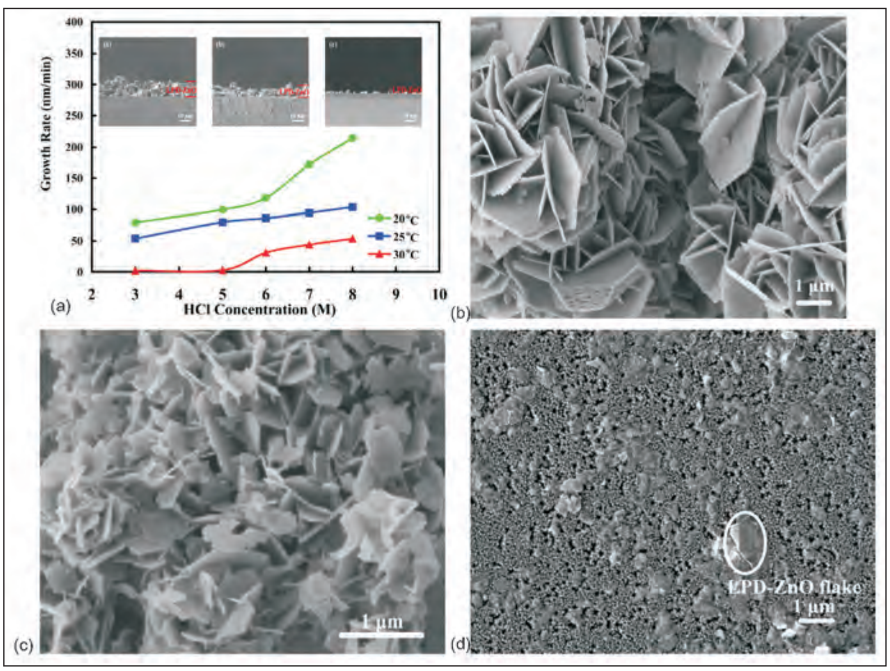

Figure 3. (a) Deposition rate of LPD-ZnO grown on Si_3N_4 as function of HCl concentration at various deposition temperatures, and FESEM images for LPD-ZnO grown at (b) 20°C, (c) 25°C and (d) 30°C. Insets of (a) show the cross-section FESEM images for LPD-ZnO grown at (a) 20°C, (b) 25°C and (c) 30°C at 6M HCl.