Design and Simulation of Multi-nozzle FDM 3D printer for fabricated Solar thin-film cells

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Abstract. In order to widely realize the personalized use of solar thin-film cells in every family, save costs and generate clean energy, our team wants to fabricate a 3D printer of solar thin-film cells. The solar film cells were 3D printed fabrication by FDM3D printer would improve their performance as battery. In this paper, for fabricate P nano-diamond/ZnO solar film cells the hot bed and nozzle of 3D printer were designed to achieve 3D printing of solar cells. A printer for fabricated solar thin-film cells was designed. PID was used to set the temperature of printer nozzle, and a refrigeration device was added to the substrate. And then finally, the printing device was simulated by SW.

1. Introduction
3D printing was an emerging technology. Due to its additive manufacturing characteristics, 3D printing was widely used in all walks of life, such as medical treatment, industrial manufacturing, prototype development[1]. The 3D model was built by the mapping software, the model was sliced by the slicing software, and then the object could be printed according to the generated G-code program. At present, several types printers commonly available on the market including FDM, SLA and SLA. FDM3D printer was used to print ABS and PLA. SLA3D printer was used to print photosensitive resin. SLS3D printer was used to print powder material. They respectively adopt the technologies of melting deposition, stereoscopic photocuring and selective laser sintering. Because most software of the 3D printers produced in China were not open source, but the software of melt deposition 3D printer was open source, so many teams designed FDM printer according to their own purposes. Currently, the common printer with single nozzle or double nozzles on the market. The single nozzle printer was used to print electrodes of solar cell, and it was found that the energy conversion rate of the electrodes with 3D printing was higher than that of the conventional solar cells[2-3]. A groove film nozzle successfully was created to fabricate perovskite thin film solar cells[4]. However the design has certain limitations. Firstly, its selection material was obtained in the low temperature solution. Secondly, it takes long time to print with single nozzle and the quality was bad. Besides, the nozzle could also be polluted by different slurries. In this paper, the hot bed and multiple nozzle of 3D printer were designed to implement 3D printing of P nano-diamond/ZnO solar film cells [5-6].
2. Assembly of FDM3D printer

The I3 printer as an example (1) first, the 3D printer base was installed, then profiles and screw were categorized according to the XYZ axis. (2) Pass an optical shaft through a bearing fixed to an aluminum plate. The hot bed was connected to a synchronizing wheel on the X-axis by a synchronizing belt. (3) The motor on the X-axis was connected with the sprinkles head by a synchronous belt. (4) The X-axis and the z-axis were connected. The z-axis lifting and moving of hot bed plane were controlled by stepper motor. (5) Limit switches were installed on xyz axis respectively to complete the assembly of 3D printer. (6) The drive and software were installed, and then debug the 3D printer according to set the parameters. The assembled 3D printer was showed as Fig 1.

![Fig 1 installation and setup of 3D printer.](image)

2.1. Modification of 3D printer

In order to solve the problem about 3D print head movement speed, extrusion speed, material dissolving rate, solidification time, printer control parameters. For fabricate P nano-diamond/ZnO solar film cells. The hot bed and multiple nozzles of 3D printer were designed to realize 3D printing of solar cells, and temperature controlled nozzles heat the printing paste to avoid the paste form solidifying. The hot bed was used to liquefy nitrogen refrigeration to accelerate the paste solidification. SolidWorks software was used to design 3D image simulation. The simulation result showed when the hot bed started to move and the nozzle dropped in height, then the multi-nozzle would begin to print, so as to achieve fast printing and improve the printing efficiency. The design modified 3D printer and simulation diagram were showed as Fig 2.

![Fig 2. Modified 3D printer.](image)

2.2. Design of 3D printer nozzle

The 3D printer nozzles structure was composed of stepper motor, feeding device, transmission device and temperature control device. The 3D printer nozzle was showed as Fig3. The stepping motor drives the screw on the coupling to rotate, and the configured printing paste was transferred to the printing nozzle with its screw. The nozzle design was equipped with temperature control device. Firstly, the design of the nozzle could realize full mixing of slurry and more uniform and controllable flow of slurry. Secondly, the nozzle could maintain the slurry temperature to avoid the slurry temperature too
low which will block the nozzle. In order to realize 3D printing of solar thin-film cells, a slot nozzle was designed and 3D Touch sensor was added to realize automatic leveling of 3D printer.

2.3. Design of temperature control
Because, the fluidity and adhesion of the material are affected by the nozzle and hot bed temperature of the printer. In order to improve the quality of products, the nozzle and the hot bed must implement temperature control. The fuzzy PID adaptive control was introduced to improve the stability of the temperature control system and overcome the uneven temperature. The nozzle and the hot bed need to be preheated to a predetermined temperature before printing. According to the error between the set temperature and the feedback temperature, the PID parameters KP, KI and KD can be used to timely correct the error. The self-calibration process of PID parameters were showed as Fig4. KP was the proportional coefficient, which could accelerate the response speed of the system and improve the regulation accuracy. The system Ki was the integral coefficient to eliminate the steady-state error and of the system. The system Kd was the differential coefficient to improve the dynamic characteristics of the system. Based on the system of Δkp, Δki, Δkd, formulate the corresponding control rules table, so as to realize the online adjustment of PID parameters.

The modified parameters were substituted into corresponding calculation formulas, and then KP, KI and KD were obtained. Using simulink the design of control simulation diagram was showed as Fig 5. Simulation results was showed as Fig 6. The system could restore stability in a short time, which fully shows that the fuzzy PID self-tuning could be used for 3D printing solar cell temperature control design.
3. Conclusion
For the P nano-diamond/ZnO solar film cells were 3D printed fabrication by FDM3D printer. The nozzle design with temperature control device could realize fully mix slurry, slurry flow more even and more controllable, and avoid the slurry, avoid pulp plug nozzle temperature too low. A slot nozzle was designed and 3D Touch sensor was added to realize automatic leveling of 3D printer. The fuzzy PID adaptive control was introduced to improve the stability of the temperature control system and overcome the uneven temperature can make the product structure was not stable, low precision. Using simulink to make the temperature control simulation, the system could restore stability in a short time.

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