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# Novel heterojunction layer assisted interfacial defect control strategy for high-performance solar cells

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**# Contribute Equally**

**Supplementary experimental section**

**Preparation of g-$C_3N_4$**: 20 g of melamine is placed in an alumina crucible cover with aluminum foil, and the temperature is raised to 550 °C (heating rate is 10 °C/min)) and held for 3 h. The product is naturally cooled to room temperature.

**Preparation of GO:** 3 g of 99.95% pure graphite sheets, 2.5 g of $K_2S_2O_8$ and 2.5 g of $P_2O_5$ were dissolved in 24 ml of concentrated sulfuric acid and then stirred at 80 °C for about 4.5 hours. After cooling, it was diluted with deionized water and continued to stir for 12 hours, and filtered with a 0.45 μm porous membrane. Subsequently, it is cleaned with deionized water to a pH value of about 7 and dried at 40 °C for 12 hours to obtain pre-oxidized graphite.

The pre-oxidized graphite powder is added to 120 ml of concentrated sulfuric acid and stirred in an ice bath at 0 °C until completely dissolved. Then slowly and continuously add 10 g of $KMnO_4$ and 1.5 g of $NaNO_3$, controlling the reaction temperature not to exceed 10 °C, after stirring for 1 hour, heating up to 35 °C and continue stirring for 2 hours. Then slowly add 125 ml of deionized water to the reaction solution, transfer the flask containing the solution to the oil bath at 98 °C, and continue stirring for 15 minutes. Then 250 ml of deionized water was added to dilute, and finally 10 ml of hydrogen peroxide (30%) was added to the reaction solution, so that the residual $KMnO_4$ and manganese dioxide reaction to produce soluble manganese sulfate. The resulting solution will turn yellow-brown in color. The product was cleaned several times with 35% concentrated hydrochloric acid, and then cleaned with deionized water to pH 6, and dispersed with ultrasonic waves to ensure that the product has a good dispersion effect. The prepared product is dried at 40 °C to obtain graphene oxide powder.

**Figure S1**

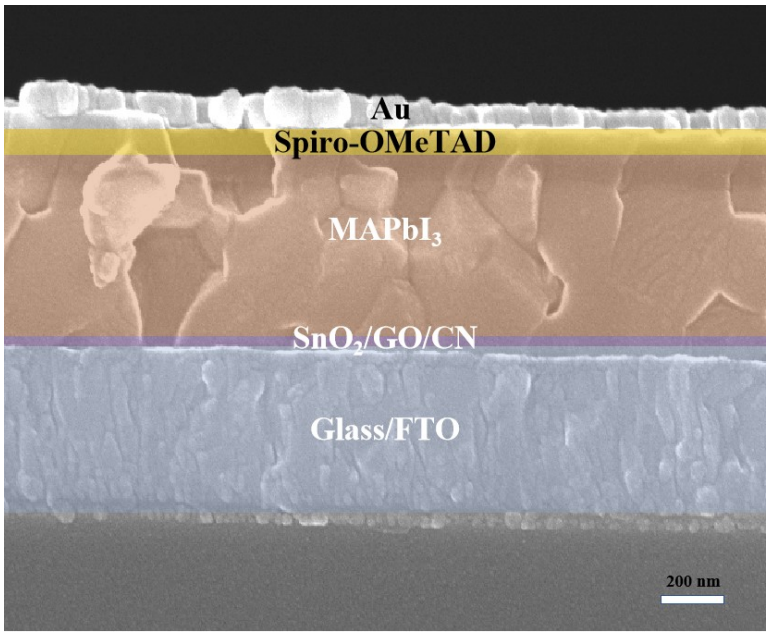


**Figure S1.** The Cross-sectional SEM image of PSCs

**Figure S2**

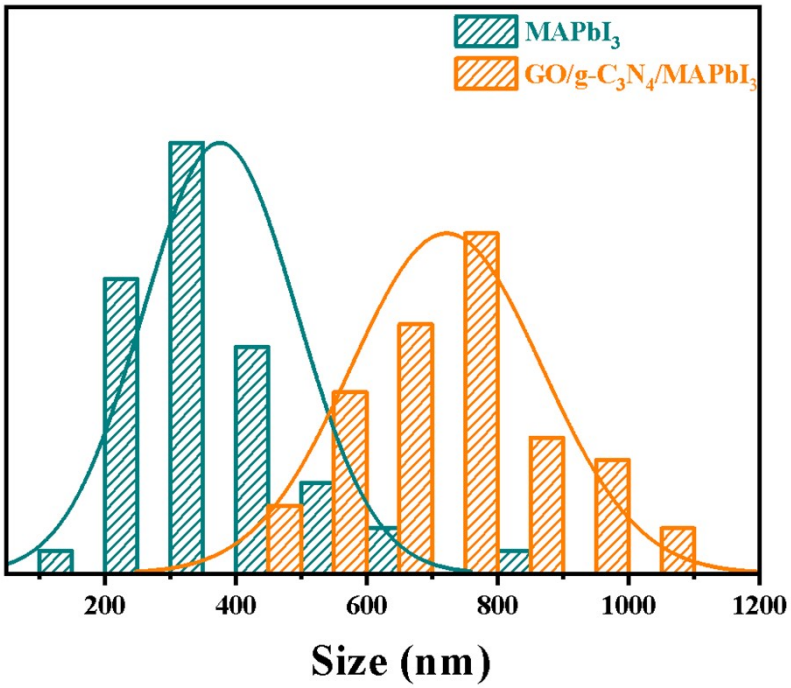


**Figure S2.** Statistic histogram distribution of crystal grain sizes for the $MAPbI_3$ film and GO/g-$C_3N_4$/$MAPbI_3$

**Figure S3**

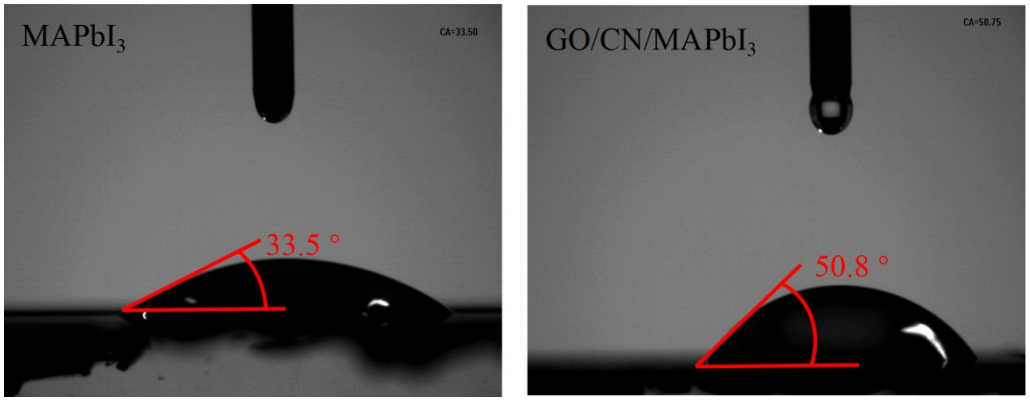


**Figure S3.** The water contact angles of $MAPbI_3$ and GO/g-$C_3N_4$/$MAPbI_3$ perovskite films

**Figure S4**

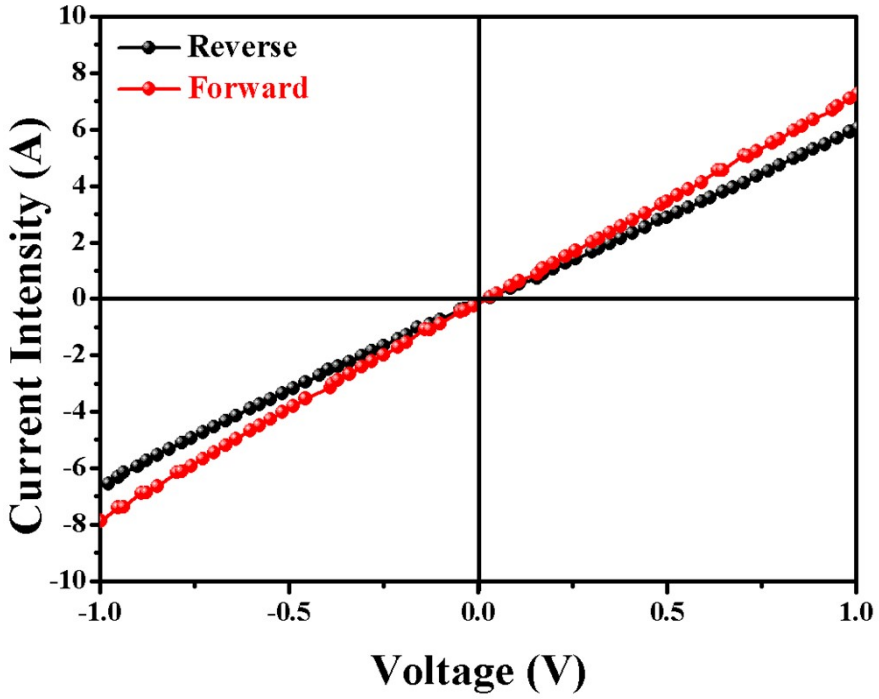


**Figure S4.** The forward/reverse IV characteristics of the "gold electrode /GO/g-$C_3N_4$/gold electrode" structure

**Figure S5**

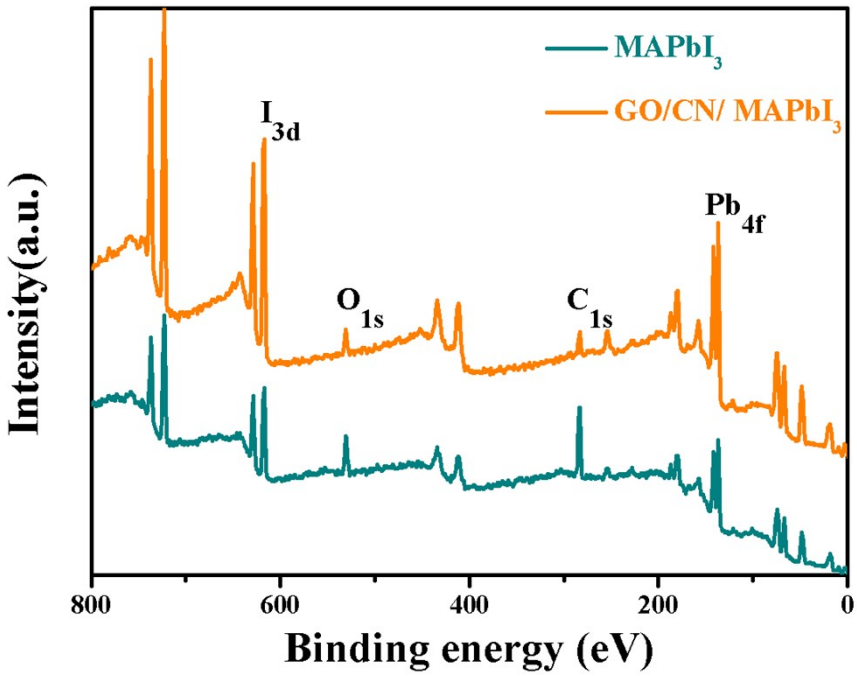


**Figure S5.** The XPS spectra of $MAPbI_3$ and GO/g-$C_3N_4$/$MAPbI_3$ perovskite films

**Figure S6**

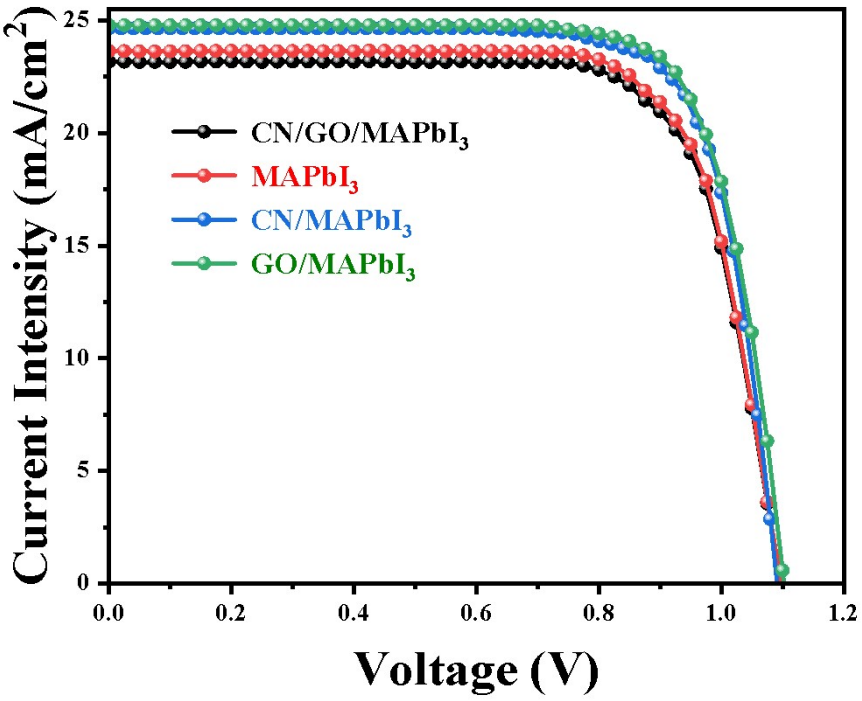


**Figure S6.** J-V curves of PSCs based on pristine, g-$C_3N_4$/GO/$MAPbI_3$, GO/$MAPbI_3$ and g-$C_3N_4$/$MAPbI_3$ perovskite films.

**Figure S7**

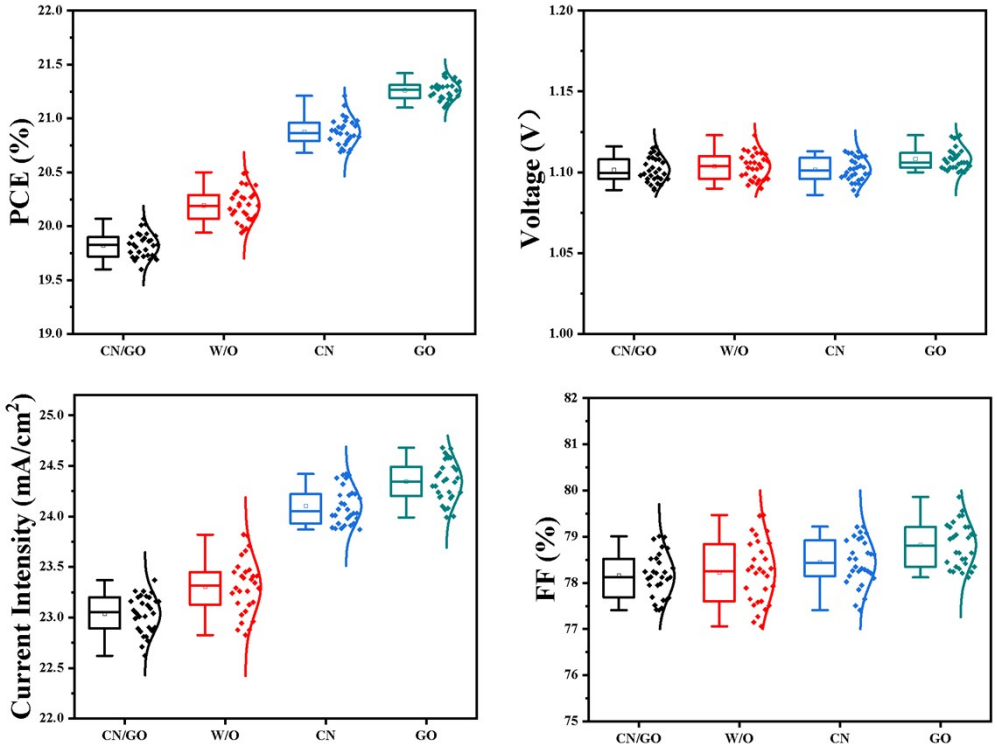


**Figure S7.** Statistical distribution of PCE, $V_{OC}$, $J_{SC}$, and FF for the pristine and GO/g-$C_3N_4$/$MAPbI_3$ PSC.

**Figure S8**

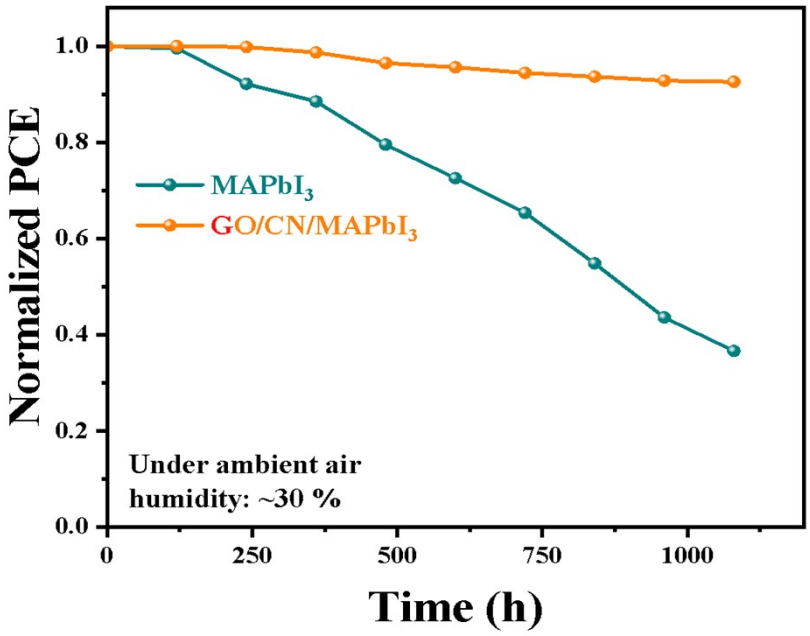


**Figure S8.** Long-term stability measurements of PSCs aging for 1080 h.

**Figure S9**

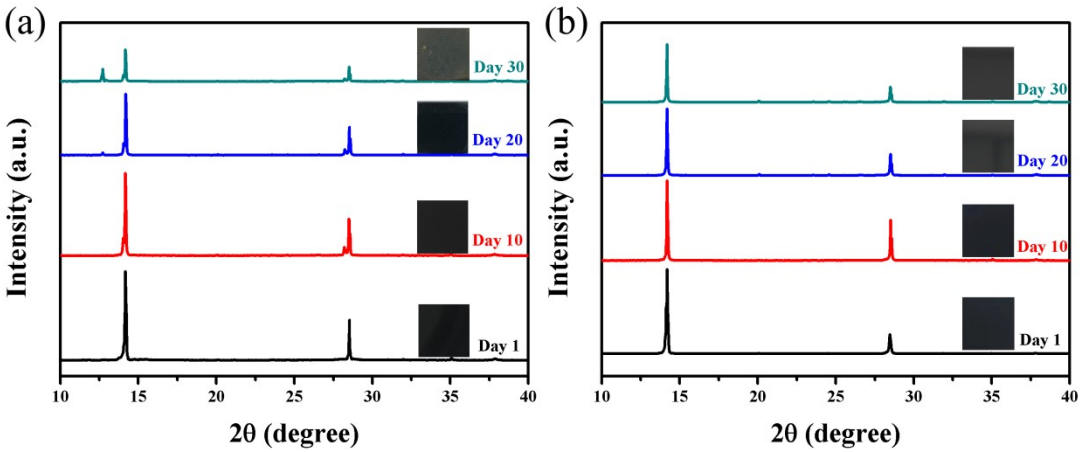


**Figure S9.** The XRD patterns of the (a) $MAPbI_3$ and (b) GO/g-$C_3N_4$/$MAPbI_3$ perovskite films in ambient air for 30 days

**Table S1**

**Table S1** Parameters calculated from the time-resolved PL spectra

| | $A_1$ | $\tau_1$(ns) | $A_2$ | $\tau_2$ (ns) | $\tau_{ave}$(ns) |
|---|---|---|---|---|---|
| **$MAPbI_3$** | 184.81 | 15.70 | 747.34 | 231.45 | 227.89 |
| **GO/CN/$MAPbI_3$** | 436.04 | 29.92 | 512.79 | 127.01 | 110.81 |

**Table S2**

**Table S2** Photovoltaic parameters of the n-i-p structure perovskite solar cells with different interface modification layer

| | $V_{oc}$ (V) | $J_{sc}$(mA cm$^{-2}$) | FF (%) | PCE (%) |
|---|---|---|---|---|
| **$MAPbI_3$** | 1.10 | 23.64 | 78.86 | 20.50 |
| **CN/GO/$MAPbI_3$** | 1.10 | 23.21 | 78.62 | 20.07 |
| **CN/$MAPbI_3$** | 1.11 | 24.38 | 79.10 | 21.21 |
| **GO/$MAPbI_3$** | 1.10 | 24.51 | 79.46 | 21.42 |
| **GO/CN/$MAPbI_3$** | 1.12 | 24.79 | 79.80 | 22.58 |