# Electronic Supporting Information

## A smartphone-based double-channel fluorescent divice for immunoassay of carcinoembryonic antigen using CuS nanoparticles for signal amplification

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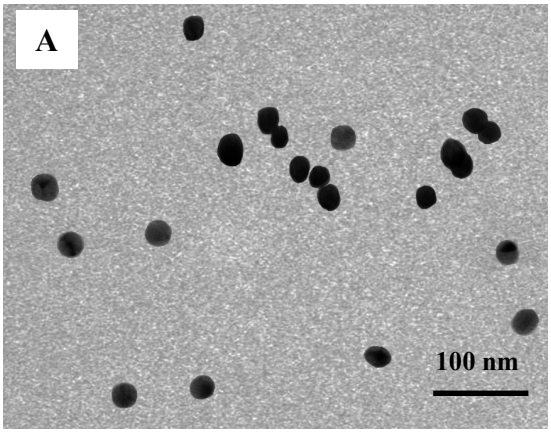


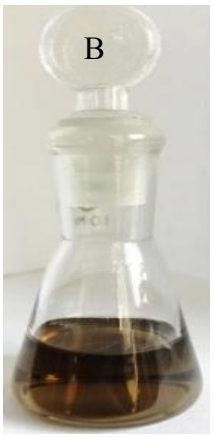


**Fig. S1.** TEM images of carboxylated CuS NPs (A). The photo of carboxylated CuS NPs suspension after being put aside for 24 hours (B).

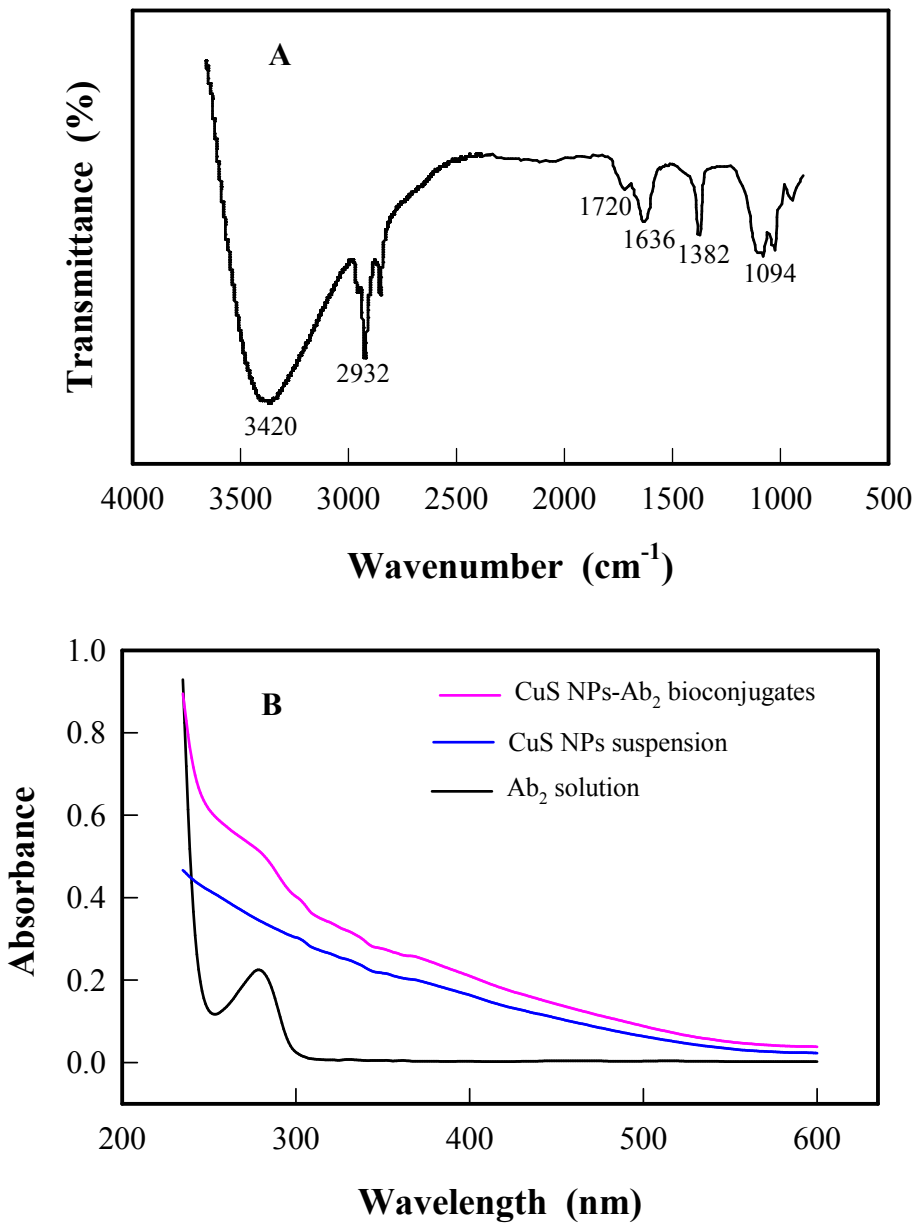


**Fig. S2.** FTIR spectrum of carboxylated CuS NPs (A). UV-Vis absorption spectra of $Ab_2$ solution, CuS NPs suspension, and CuS–$Ab_2$ bioconjugates (B).

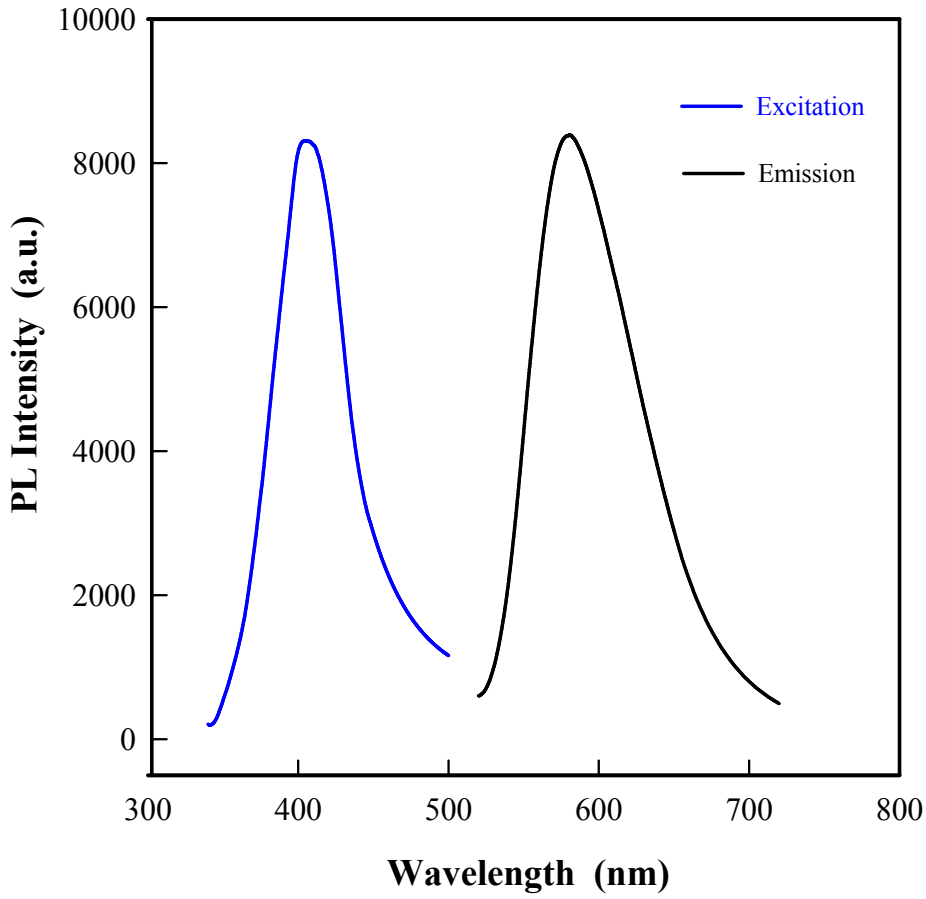


**Fig . S3** Excitation and emission spectra of DAP. Concentration of DAP was 0.4 μM, pH=6.0.

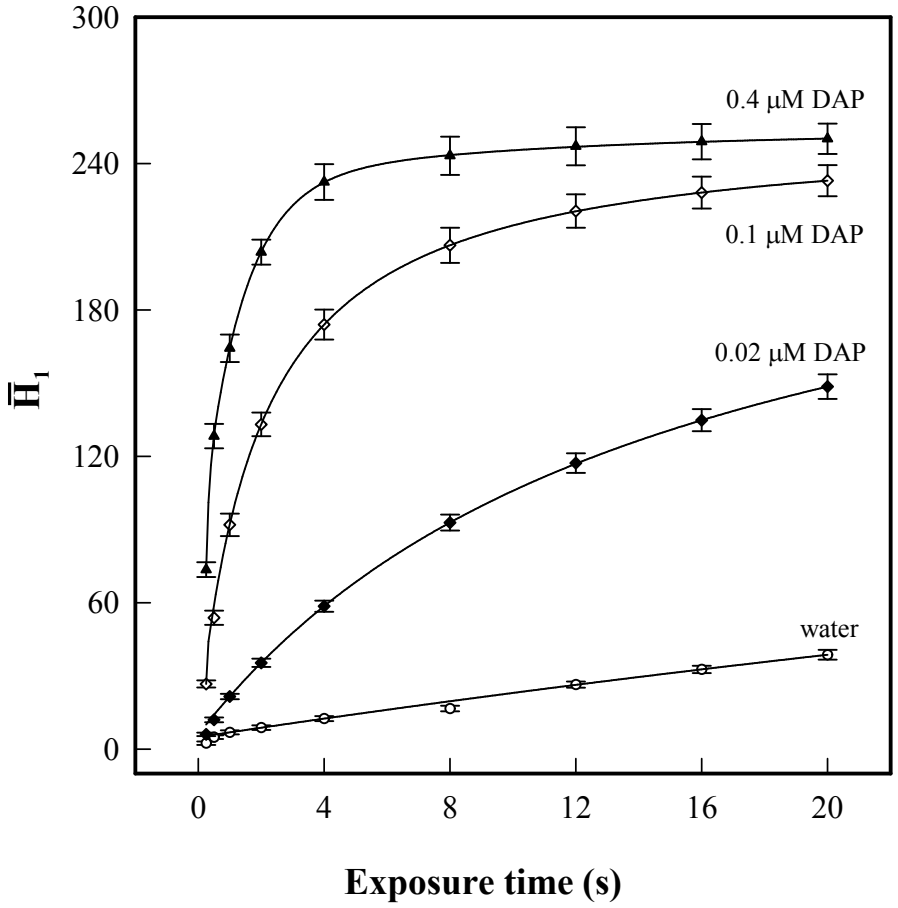


**Fig. S4** Influence of the exposure time on averaged brightness of the fluorescence images of DAP solutions (ISO = 400).

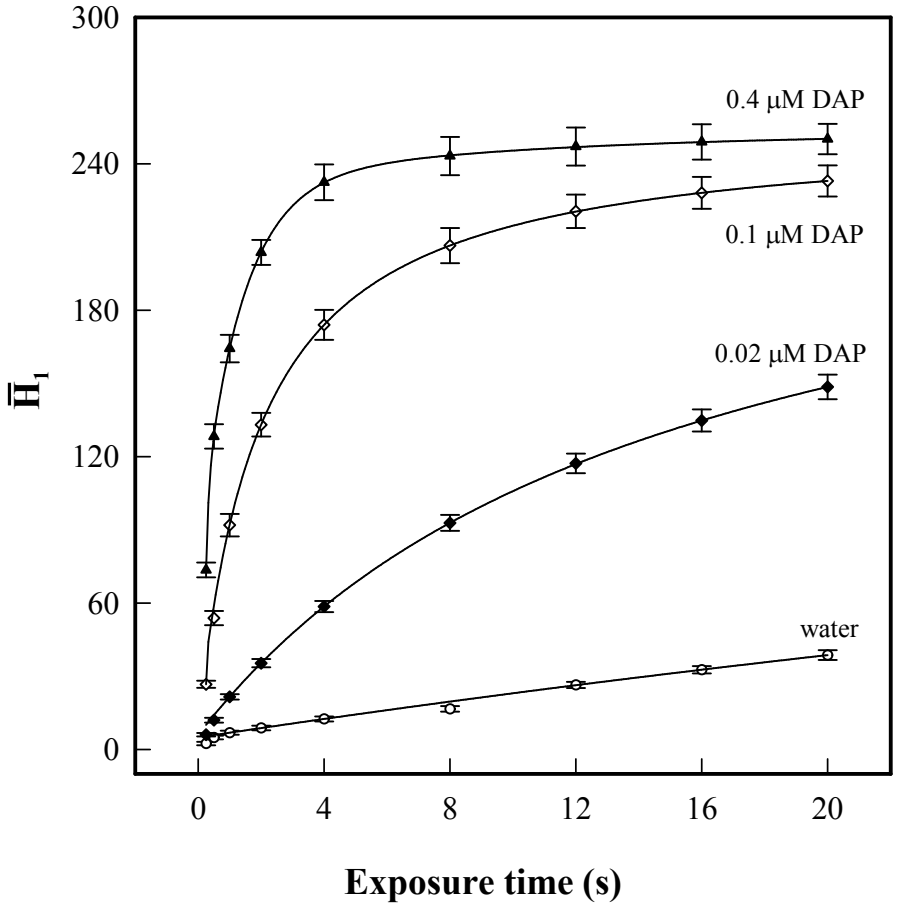


**Fig. S5** Influence of the ISO value on averaged brightness of the fluorescence images of DAP solutions (exposure time = 0.5 s )

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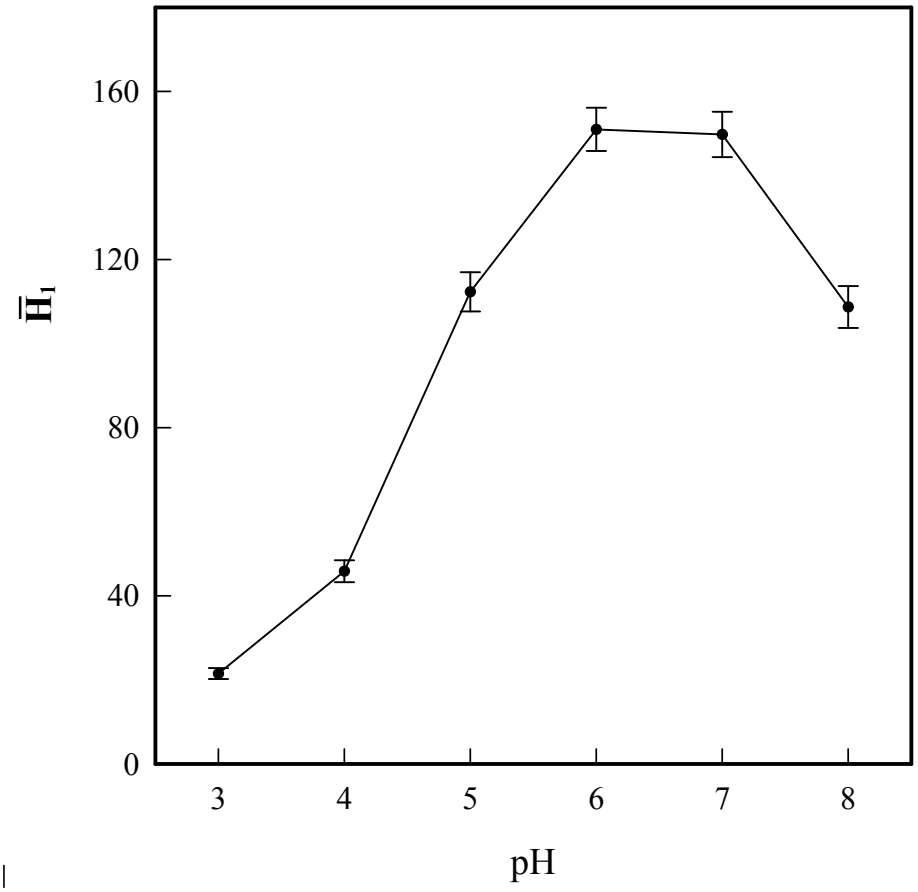


**Fig. S6** Influence of pH on the image intensity in 0.4 μM PAD solution. Exposure time = 0.5 s, ISO = 400.

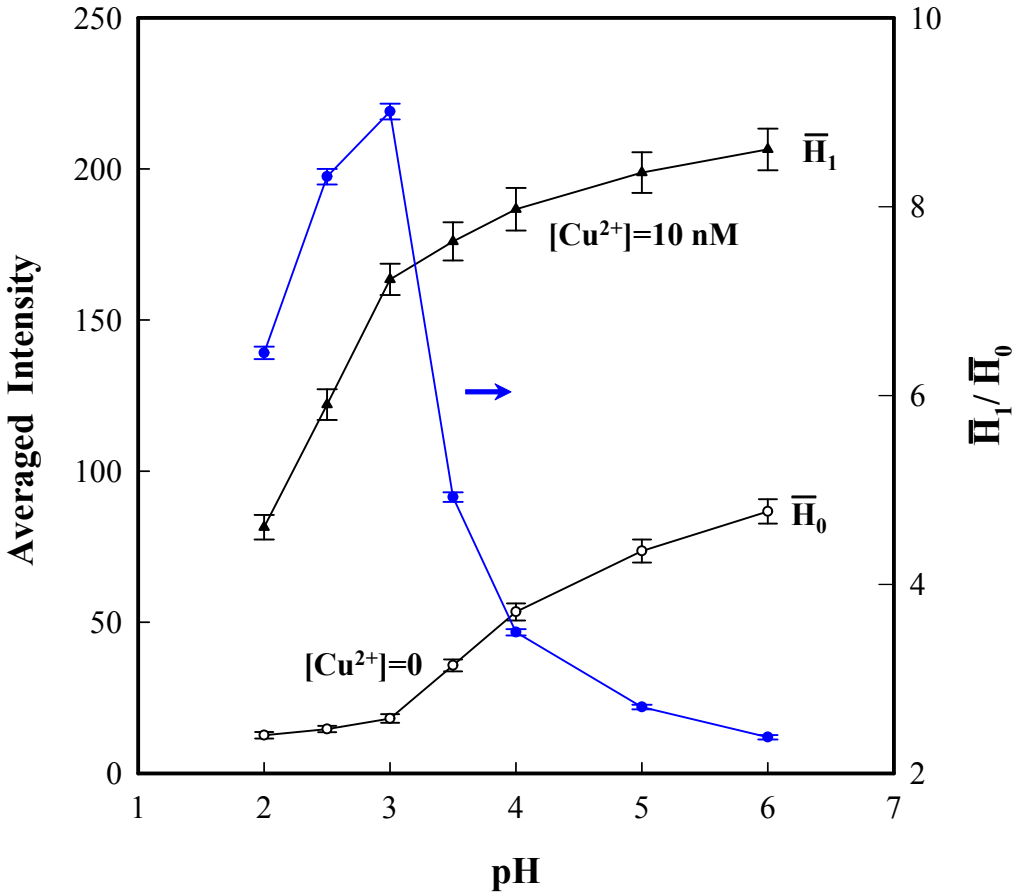


**Fig. S7** Influence of pH on the image intensity in the catalytic reaction system. Reaction conditions: Temperature = 80 °C, reaction time = 15 min, [OPD]=0.8 mM, measurement condition: pH=6; exposure time = 0.5 s, ISO=400, room temperature.

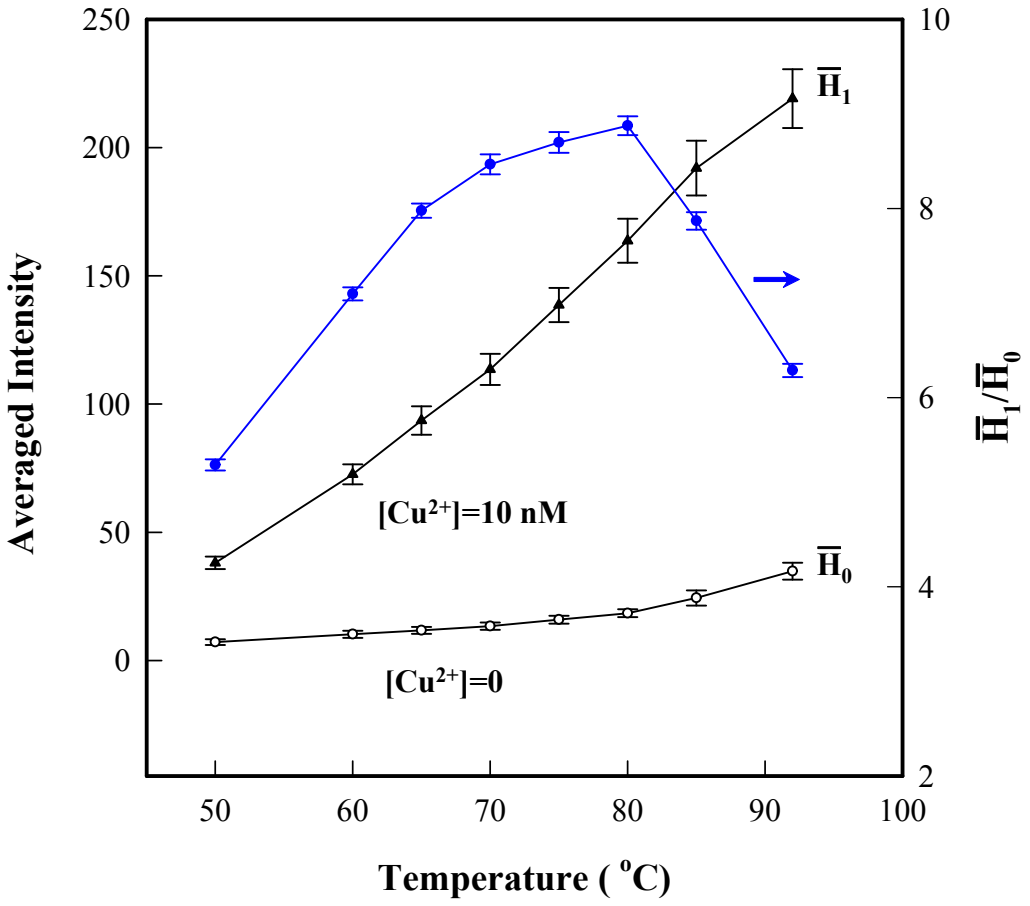


**Fig. S8** Influence of temperature on the image intensity in the catalytic reaction system. Reaction conditions: pH = 3.0, reaction time = 15 min, [OPD]=0.8 mM, measurement conditions are the same as **Fig.S7.**

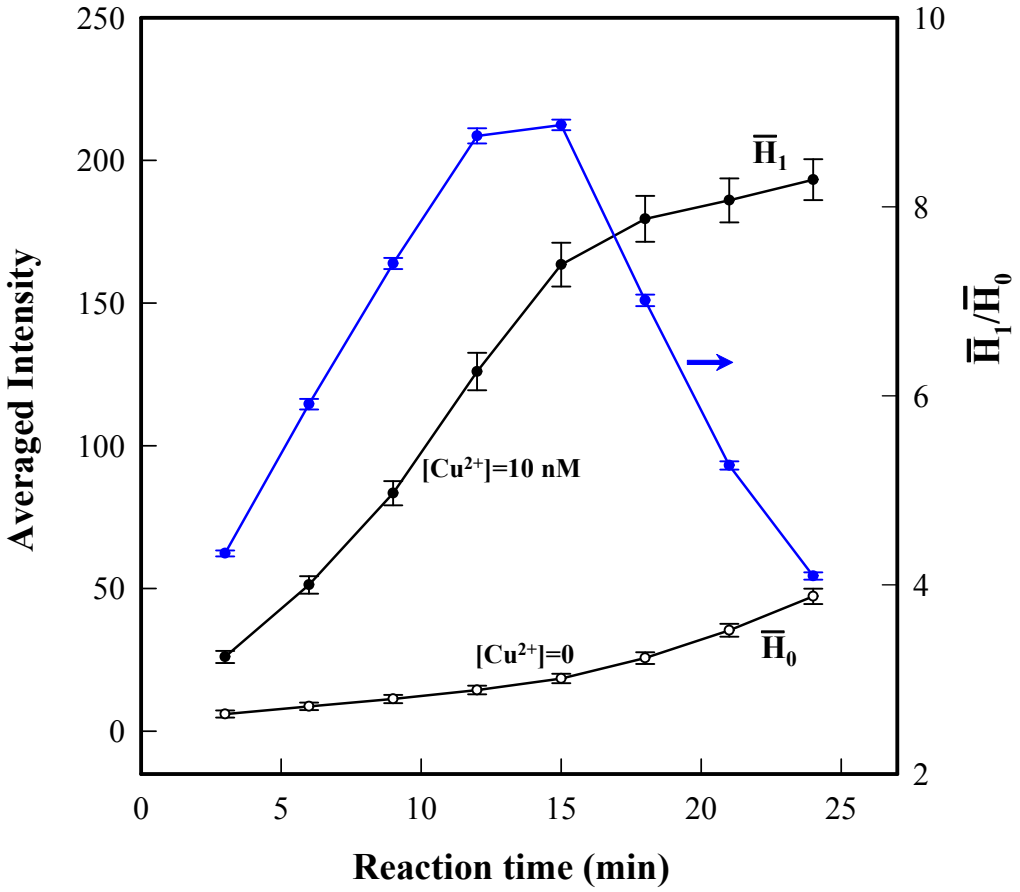


**Fig. S9** Influence of reaction time on the image intensity in the catalytic reaction system. Reaction conditions: Temperature = 80 °C, pH = 3.0, [OPD]=0.8 mM, measurement conditions are the same as **Fig.S7.**

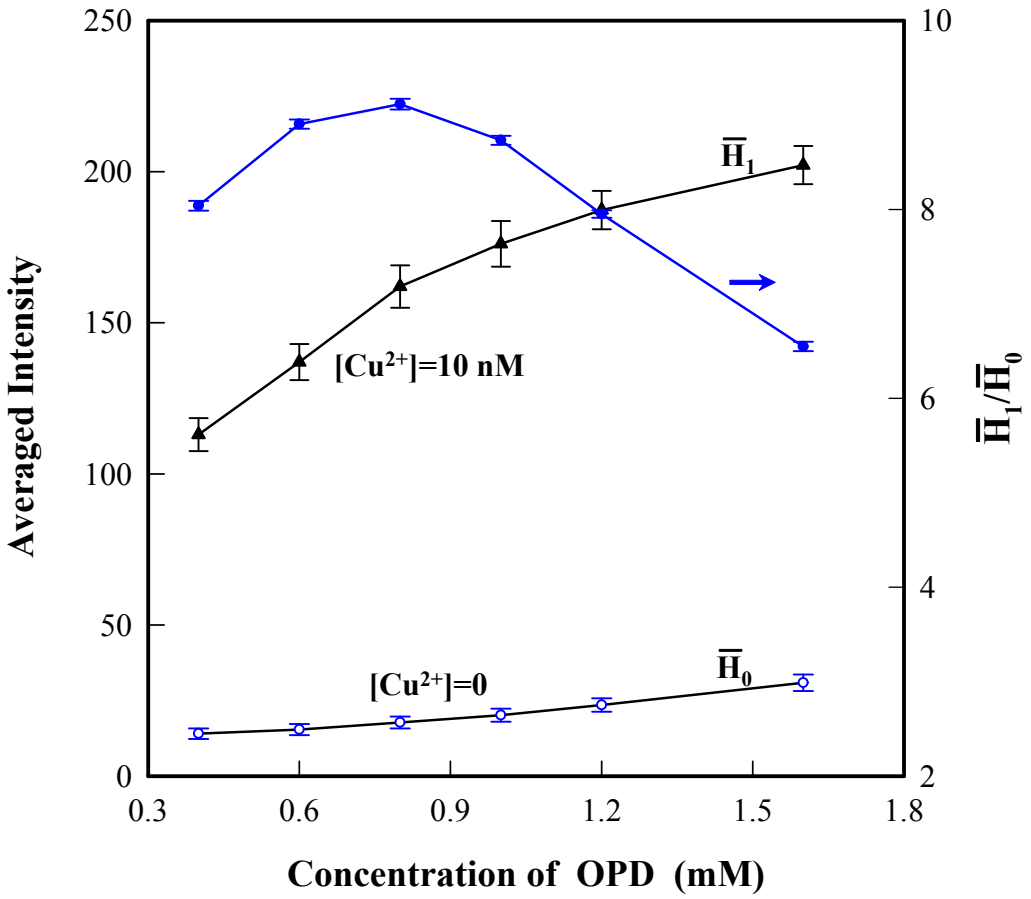


**Fig. S10** Influence of OPD concentration on the image intensity in the catalytic reaction system. Reaction conditions: Temperature = 80 °C, pH = 3.0, reaction time = 15 min, measurement conditions are the same as Fig.S7.

**Table S1**. Comparison of analytical performance of some immunoassay methods for CEA detection

| Immunoprobs * | Methods ** | Linear range (ng $mL^{-1}$) | LoD (ng $mL^{-1}$) | Refs. |
|---|---|---|---|---|
| $Ab_1$-CEA | CI | 0.0001–10 | $1\times10^{-4}$ | 1 |
| CEA-Ag@Au-$Ab_1$ | DLS | 0.06– 50 | 0.04 | 2 |
| GO-$Ab_1$-CEA-Apt.-Ag NCs-HRP | EC | 0.001–10 | $5\times10^{-4}$ | 3 |
| 3D-G-Con A- HRP-$Ab_1$-CEA | EC | 0.1–750 | 0.09 | 4 |
| GO-$Ab_1$-CEA-$Ab_2$-AuNPs/g-$C_3N_4$ | ECL | 0.001 –10 | $4\times10^{-4}$ | 5 |
| Apt.-CEA-Apt.-Ru@$SiO_2$- Au NPs | ECL | $5\times10^{-6}$–0.05 | $1.5\times10^{-6}$ | 6 |
| Au NPs $Ab_1$-CEA | EIS | 0.05 –80 | 0.001 | 7 |
| CEA-Au@Ag-$Ab_1$ | Fluorescence | 0.02–0.2 | 0.01 | 8 |
| QBs-Ab1 | ICTS | 1–100 | 0.04 | 9 |
| $Fe_3O_4$-Ab1-CEA-$Ab_2$-$CeO_2$@$SiO_2$ | ICP-MS | 0.001–5 | $3.6\times10^{-4}$ | 10 |
| $Ab_1$-CEA-$Ab_2$-Cy3 | LIF | 0.3–100 | 0.01 | 11 |
| $Ab_1$-CEA-$Ab_2$-Au NPs | Love wave | 0.01~10 | 0.004 | 12 |
| $Ab_1$-CEA-$Ab_2$-Dynabeads | MI | 0.001–10 | 0.001 | 13 |
| ZnO-$Ab_1$-CEA-$Ab_2$- CdS@$Cu_2O$ | PEC | 0.001– 80 | $4\times10^{-4}$ | 14 |
| $Ab_1$-CEA-$Ab_2$-Au NPs | SAW | 1–16 | 1 | 15 |
| $Ab_1$-CEA-$Ab_2$-Au NPs | SPR | 1–60 | 1 | 16 |
| MB-$Ab_1$-CEA -$Ab_2$-$Eu^{3+}$ | TRFIA | 1–1000 | 0.5 | 17 |
| $Ab_1$-CEA-$Ab_2$-CuS NPs | Smartphone fluorescence | $1\times10^{-4}$～0.001 | $5\times10^{-5}$ | This work |

* Apt.: aptamer, GO: graphene oxide, MB: magnetic beads, QBs: quantum dot nanobeads.

** CI: contactless impedance, DLS: dynamic light scattering, EC: electrochemistry, ECL, electrochemiluminescence, EIS: electrochemical impedance spectroscopy, ICP-MS: inductively coupled plasma-mass spectrometry, ICTS: immunochromatographic test strip, LIF: laser-induced fluorescence, MI: magnetoimpedance, PEC: photoelectrochemical, SAW :surface acoustic wave, SPR: surface plasmon resonance, TRFIA: time-resolved fluoroimmunoassay.

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