Supporting Information

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Materials. All chemicals and solvents are reagent or HPLC grade, used as received, and purchased from Sigma-Aldrich (Steinheim, Germany) unless stated otherwise. The deionized water used is purified using a Millipore water purification system with minimum resistivity of 18.0 MΩ-cm.

Synthesis of Ni@ZIF67. Typically, 2.910 g of Co(NO₃)₂•6H₂O and 0.073 g of Ni(NO₃)₂•6H₂O were firstly dissolved in 250 mL methanol to form solution A. 6.560 g of 2-methyl imidazole was dissolved in 250 mL methanol to form solution B. Then, quickly pour solution A into solution B, shake it vigorously and leave it to stand overnight. The purple precipitates were centrifuged at 11000 rpm, washed with ethanol, and dried in a vacuum at 338 K overnight.

Synthesis of Ni@Co-NC. Following a typical procedure, the dicyandiamide (100 mg) and Ni@ZIF67 (100 mg) were separately placed on a corundum boat. The corundum boat was firstly heated in a tube furnace under argon environment to 450 °C (at 2 °C /min) for 8 h, then was further heated to 800 °C (at 5 °C/min) for 2 h. The yielded Ni@Co-NC were collected after cooling. Similarly, Co-NC was synthesized using the ZIF67 as a precursor by the same protocol without adding Ni(NO₃)₂•6H₂O. As a comparison, cousin materials without nanohooks, Ni@ZIF67-C, were prepared by the same protocol without adding dicyandiamide (DCD) during pyrolysis. The underlying mechanism can be attributed to the in-situ thermal chemical vapor deposition (T-CVD) process. Briefly, the excess carbon produced by the pyrolysis of the precursor can be catalyzed by the transition metals (Co, Ni, Fe) in a reducing atmosphere (like H₂, CO, and NH₃) to form carbon nanotubes (CNTs). Excess carbon will precipitate on the surface of catalysts, and then diffuses into the catalyst, and ultimately nucleates to form the CNT at the edges of the catalyst. In this article, DCD provides the reductive NH₃ and is also one of the sources of nitrogen and carbon. During the carbonization, the in-situ generated Ni/Co nanocrystals catalyzed the excess carbon species to form nanohook-like CNTs under the NH₃ atmosphere.

Material characterizations. A Discover D8 (Bruker) was used to measure powder X-ray diffraction patterns. High-resolution transmission electron microscopy (HRTEM) and EDS were performed using an FEI Tecnai G2 F20 S-TWIN (200KV). SEM testing was carried out using a Hitachi SU8030. XPS
was performed using a K-alpha X-ray photoelectron spectrometer system (Thermo Scientific) with a Hemispheric 180° dual-focus analyzer with a 128-channel detector. XAS spectra at the cobalt K-edge were collected at the BESSY synchrotron (Berlin, Germany) at beamlines KMC-3.

**Photothermal conversion of Ni@Co-NC.** To investigate the photothermal conversion performances of the Ni@Co-NC, the temperatures of Ni@Co-NC under suspensions with different concentrations (62.5 and 31.3 μg/mL) were measured by a thermal imaging camera (NEC Avio Thermo Tracer TH9100). The samples were dispersed in PBS (0.2 mL). Then, a laser beam (FC-D-808, CNI Optoelectronics Technology Co. Ltd., Changchun, China) focused on the suspension at a power density of 1 W/cm² for 7 min in a uniform distance of 5 cm. At the same time, the infrared thermal images were taken under certain time intervals. PBS was used as a control. The experiments were repeated at least three times to get an average value.

**Peroxidase-like activity of Ni@Co-NC.** To monitor the peroxidase-like property of the Ni@Co-NC, the 3,3,5,5-tetramethylbenzidine (TMB) molecular probe was utilized, and reactions were carried out in 0.1 mL acetate buffer solution (0.1 M, pH = 4.0), and the final concentrations of TMB, H₂O₂, and Ni@Co-NC were 1 mM, 10 mM, and 33 μg/mL, respectively. After 5 min reaction time with/without laser irradiation (1 W/cm²), photos were taken, and the UV-vis absorption spectra were determined with a plate reader Tecan (Infinite M200 Pro).

The steady-state kinetic assay was performed at room temperature. For kinetic parameters, the experiments were carried out in 100 μL NaAc buffer containing 62.5 μg/mL Ni@Co-NC, 832 μM TMB, and a series of concentrations of H₂O₂ ranging from 0 to 1000 mM, or containing 62.5 μg/mL Ni@Co-NC, 100 mM H₂O₂, and a series of concentrations of TMB ranging from 0 to 832 μM. The absorbances of all reactions were monitored in a time-scan mode at 652 nm through a plate reader Tecan (Infinite M200 Pro), and the Michaelis–Menten constant was calculated according to the Michaelis–Menten saturation curve by GraphPad Prism 7.0 (GraphPad Software).

**•OH generation activity of Ni@Co-NC.** Terephthalic acid (TA) was used as a fluorescent probe that easily reacts with •OH to form a highly fluorescent product, 2-hydroxy terephthalic acid (HA). In a typical procedure, 30 μg of Ni@Co-NC was dispersed in 1.5 mL of PBS (pH~7.4) or NaAc-HAc
Then, the Ni@Co-NC-buffer dispersions were mixed with 1.5 mL of 6 mM TA solution containing 100 μM H₂O₂ for 12 h in the dark, and finally, the changes in the 435 nm fluorescence emission peak were recorded using a Fluorescence Spectrometer Jasco FP-6500.

Besides, electron spinning resonance (ESR) measurements were also conducted using a Bruker ESR EMX Plus to test •OH generation activity of Ni@Co-NC under different pH conditions with/without laser irradiation. 5,5-Dimethyl-1-pyrroline-N-oxide (DMPO) spin-trapping adduct was used to detect •OH generation. Specifically, 20 μL of 10 mM H₂O₂, 20 μL of DMPO, and 200 μL of Ni@Co-NC-buffer solution with a 1 mg/mL concentration were mixed. The ESR spectra were recorded 5 min after the reaction. For the NIR groups, 808 nm laser irradiation (1.0 W/cm², 5 min) was employed.

**Culture and harvest MRSA biofilm.** MRSA (ATCC 43300) was used in this research. Regarding MRSA biofilm culturing, a MRSA suspension (100 μL, 10⁸ CFU/mL) and a lysogeny broth medium (LB, 100 μL) were placed in ibidi 8-well slides, and then they were cultured at 37 °C. Twenty-four hours later, the medium was removed, and the unattached bacteria were gently washed away with sterile PBS three times, and the resulting biofilm on ibidi 8-well slides was harvested. The in vitro experiment's pH was adjusted by adding PBS solution (pH 5.5, 10 mM) when required.

**In vitro bacteria/biofilm binding tests.** Octadecyl rhodamine B chloride (R18) was used as labeling dye for Ni@Co-NC, and fluorescein isothiocyanate (FITC) was used as labeling dye for bacteria. For bionanocatalysts labeling, typically, 5 μL of 0.1 mM ethanol solution was mixed with 95 μL of 1 mg/mL Ni@Co-NC-PBS dispersion. After incubation in the dark for 45 minutes, the R18-labeled bionanocatalysts were washed by PBS 3 times to remove the excess dye. Typically, for bacteria labeling, 0.5 mg of FITC was dissolved in 1 mL of PBS (pH~8) as a labeling buffer. Afterward, a certain amount of labeling buffer was introduced into glutaraldehyde-fixed bacteria/biofilm, and the staining procedure lasted for 45 minutes in the dark. Then, the FITC-labeled bacteria/biofilm were washed by PBS 3 times to remove the excess dye.

For the in vitro planktonic bacteria binding tests, FITC-labeled MRSA solution (~10⁸ CFU/mL) was introduced into the lysine pre-treated ibidi 8-well slides for 1 min and was pipetted out to leave a thin layer of MRSA on the well surface. Then, R18-labeled Ni@Co-NC was introduced into the well
and a SP8 confocal microscope (Leica, Germany) was used for in-situ monitoring the interaction between bacterial and bionanocatalysts as increasing incubation time (5-30 min). While for biofilm binding test, a biofilm (24 h aged) was grown in ibidi 8-well slide and labelled by FITC. After incubation with bionanocatalysts for 30 minutes, a PBS washing step was performed to remove uncoupled bionanocatalysts. Then the fluorescent and bright-field images were acquired on a SP8 confocal microscope (Leica, Germany). For SEM sample preparation, the bionanocatalysts-bacteria solution was first centrifuged at 3000 rpm 3 times to remove the uncoupled bionanocatalysts. Subsequently, the pellet was fixed by 2.5% glutaraldehyde overnight at 4 °C and subjected to gradient dehydration using ethanol series (30%, 50%, 70%, 90%, and 100%, 10 min of each). Then dropped it onto aluminum foil and dried it at room temperature.

**In vitro planktonic bacterial killing tests.** Typically, the samples Ni@Co-NC were firstly dispersed in LB media (pH~5.5). Then, 100 μL of sample dispersions with a series of dilution times and H2O2 with the final concentration of 100 μM were introduced into 100 μL of ~10^6 CFU/mL bacterial suspensions. After incubation for 30 minutes under mild shaking, the bacteria/bionanocatalysts' suspensions were irradiated by an 808 nm laser (1 W/cm^2) for 5 min. After near-infrared irradiation, the suspensions were incubated at 37 °C for 6 h. Experimental groups without laser irradiation and H2O2 were carried out as the control. At last, the bactericidal ratio for the samples under different conditions was studied via agar plate counting. The bacterial suspensions were diluted and cultured on agar plates for 12 h to count the bacterial colonies. We calculated all bactericidal ratios by comparing the treatment groups with control groups in the same intervention condition. For example, groups treated by Ni@Co-NC with H2O2 were compared to control with H2O2 to obtain the bactericidal ratio. Moreover, both SEM and cryo-TEM (Talos Arctica, Thermofisher, USA) were utilized to observe the bactericidal actions of Ni@Co-NC. The protein leakage amounts of bacteria after treatment were measured using Pierce™ BCA Protein Assay Kit.

**In vitro anti-biofilm tests.** Typically, for 3D confocal observation, 200 μL of Ni@Co-NC-PBS dispersion (125 μg/mL, pH~5.5) was introduced into 24-hour-aged biofilm in ibidi 8-well slides. After incubation for 30 minutes, H2O2 with a final concentration of 100 μM was introduced to each well, and 5-min laser irradiation was conducted. Experimental groups without laser irradiation and H2O2
were carried out as the control. After incubation at 37 °C for 12 h, the biofilms were gently washed by PBS three times and then stained by LIVE/DEAD® BacLight Bacterial Viability Kits. The 3D Z-stack fluorescent and orthogonal-stack images were acquired on the SP8 lighting confocal laser scanning microscope (Leica, Germany). The fluorescent intensities are analyzed by ImageJ pro. The biofilm viability is quantified by comparing the live bacterial intensity with the total intensity of live and dead bacterial intensity.

Furthermore, an isothermal microcalorimetry instrument (IMC, Thermal Activity Monitor, Model 3,102 TAM III, TA Instruments, New Castle, DE, USA) was utilized to monitor the recurrence of biofilm after treatment. IMC is a non-destructive method that allows for the monitoring in the microwatt range of any exothermic or endothermic reaction related to the physical, chemical, and biological process in the tested sample. IMC enables precise real-time monitoring of the heat flow related to microbial metabolism. As long as the bacteria proliferate, their metabolism heat flow can be precisely recorded by IMC; therefore, in this study, we think IMC is a good method to test whether biofilm recurrence will happen after treatment. Briefly, the treated biofilms grown in 96-well plates were detached and transferred into ampoules containing 3 mL of LB media. Afterward, airtight sealed ampoules were sequentially introduced into the microcalorimetry channels and lowered to an equilibrium position for 15 min to reach a temperature of 37 °C. The heat generated in real-time by recovering bacteria within biofilm after treatment was continuously measured. Heat flow (μW) was measured at 120 s-intervals are recorded for 24 h.

**Cytotoxicity.** Human skin keratinocyte cell line HaCaT was chosen as model cell line to investigate the cells toxicity of the bionanocatalysts. HaCaT cells were grown in Eagle's minimal essential medium (DMEM) supplemented with 10% fetal bovine serum, 4.5 g/L glucose, 2 mM L-glutamine, 100 mg/ml streptomycin, and 100 units/ml penicillin) in a 96-well plate at 37 °C and 5% CO₂. The cytotoxicity was then measured via CCK-8 assay according to the manufacturer’s instruction. Briefly, after being exposed to the bionanocatalysts for 24 h, the cells were washed twice with medium, and then 10 μL of CCK-8 solution was introduced to each well. After 3 h of incubation, the optical density at 450 nm of each well was measured by a microplate reader, and the viability was calculated by dividing the treated group’s absorbance by the control group’s absorbance.

**In vivo biofilm eradication.** All animal experiments were performed humanely in compliance with guidelines reviewed by the animal ethics committee of West China Hospital (approval number:
2021024A). For in vivo experiments, healthy adult New Zealand white rabbits (2.5-3.0 Kg, male, Chengdu Dossy Biological Technology Co. Ltd. (China)) were used. After anesthetized with 2% sodium pentobarbital, a small wound (about 10 mm in diameter) was created on the rabbit epidermis, then 0.5 mL MRSA bacterial suspension ($1 \times 10^8$ CFU/mL) was dropped onto the wound. After cultured for 1 day, activated Ni@Co-NC treatment was conducted. In brief, Ni@Co-NC suspension (1 mg/mL) was dropped onto the infected wound. Then, the wound was irradiated by a laser (2.5 W/cm$^2$) for 2 min to achieve antibacterial disinfection. After the near-infrared treatment, the wound was washed by saline 3 times. During the antibacterial process, photothermal images were taken by a thermal imaging camera (NEC Avio Thermo Tracer TH9100). For comparison, groups of vancomycin (16 µg/mL), H$_2$O$_2$ (100 µM), Ni@Co-NC+laser, and Ni@Co-NC+H$_2$O$_2$ are also conducted to evaluate the in vivo biofilm eradication efficacy of activated Ni@Co-NC.
**Figure S1.** SEM images of precursors (a, d) and corresponding bionanocatalysts without adding DCD during pyrolysis (b, e) and with adding DCD (c, f).
Figure S2. Morphology of Ni@Co-NC bionanocatalysts with different mass ratios of Ni@ZIF67 and DCD.

As shown in Figure S2, the nanohooks became denser with the increasing amount of DCD. It is noticed that adding too much DCD may cause the self-entanglement of bionanocatalysts; and when the DCD amount is insufficient, for example Ni@ZIF67 : DCD=2 : 1, the number of CNTs on the surface is very limited. By tuning the mass ratio of Ni@ZIF67 : DCD, it is found that the 1 : 1 mass ratio can yield the optimal nanohook structure (Figure S1c).
Ni@ZIF67 showed the same XRD pattern as the ZIF67 (CCDC code GITTOT), indicating trace amount of nickel doping did not change the crystal structure of ZIF67.
Figure S4. XPS data of Ni@Co-NC. High-resolution XPS spectra of (a) Co 2p, (b) N 1s and (c) Ni 2p. (d) The atomic ratios of C, N, O, Co, and Ni were calculated from XPS data.
Figure S5. Catalytic •OH generation activities of Ni@Co-NC when pyrolyzed at 700 °C, 800 °C, and 900 °C, respectively. Unless otherwise noted, Ni@Co-NC in this article refers to Ni@Co-NC-800.
Figure S6. (a) The relative POD-like activity of Ni@Co-NC under four different conditions, from left to right: 1. room temperature (23 °C); 2. exposed to laser but in 23 °C thermostatic water bath, which allowed temperature maintained at around 23 °C over the measurement; 3. in 55 °C thermostatic water bath; and 4. heated up to 55 °C by laser. The relative POD-like activity was calculated by the absorbance at 652 nm using TMB as substrate. (b) Photothermal heating profiles of Ni@Co-NC, Co-NC, and Ni@ZIF67-C exposed to NIR laser at a power density of 1 W/cm². (c) Dose-dependent POD-like activity of Ni@Co-NC. (d) POD-like activity and (e) relative POD-like activity calculated from UV-vis spectra at the absorbance of 652 nm of Ni@Co-NC and Ni@ZIF67-C. All experimental data are displayed as the average values (mean ± SD, n = 3). Asterisks indicate significant differences (*P<0.1, **P < 0.01, ***P < 0.001), and n.s. indicates a non-significant difference.

Discussion of photothermal ability: the photothermal property of Ni@Co-NC originates from its abundant sp²-carbon structures. Just like sp²-carbons in CNTs and graphene, such structures can absorb and convert the near-infrared (NIR) light to heat, also named as photothermal agents. Therefore, we have calculated the surface sp²-carbon contents of Ni@Co-NC, Co-NC, and Ni@ZIF67-C from the XPS C1s data. Due to the covering of sp²-carbon-riched CNT nanohooks, both the Ni@Co-NC and Co-NC showed higher sp²-carbon contents than Ni@ZIF67-C (Figures S7a and S7c). From the
photothermal heating curves, we found that Co-NC exhibited comparable photothermal conversion ability with Ni@Co-NC, whereas the Ni@ZIF67-C showed relatively weak heating ability (Figure S6b). Therefore, by introducing more sp$^2$-carbons on the surface, these nanohooks enhanced the photothermal ability of bionanocatalysts.
Figure S7. High-resolution XPS (a) C1s and (b) N1s data and corresponding (c) carbon contents and (d) nitrogen contents in Ni@Co-NC and the comparison samples.

Discussion of catalytic ability: we found that after anchoring with nanohooks, the relative peroxidase-like activity of bionanocatalysts slightly increased for about 25% (Figures S6d and S6e). Furthermore, the total superficial nitrogen amount increased significantly after anchoring nanohooks from XPS high-resolution N1s data. Especially, the pyridinic N contents of Ni@Co-NC increased to around twice that of Ni@ZIF67-C (Figures S7b and S7d), indicating the nanohooks enriched metal-Nₓ and N-doped carbon sites of bionanocatalysts, which can also be demonstrated from STEM-based elemental line scanning (Figure 1f). Previous studies have revealed that the N-doped carbons and metal-Nₓ sites had good POD-like activity,⁷⁻⁸ therefore, we speculate that the nanohooks structures can enhance POD-like catalytic activity by enriching the superficial N-doped carbons and metal-Nₓ sites of bionanocatalysts.
Figure S8. Photographs of Ni@Co-NC with different concentrations and precipitation times in PBS.

We found that 62.5 μg/mL of Ni@Co-NC showed good stability over 6 h, and it can still be stable for 2 h at a concentration of 125 μg/mL. While when the concentration increased to more than 250 μg/mL, the Ni@Co-NC precipitated much faster.
Figure S9. Steady-state kinetic assay of Co-NC for g) TMB and h) H₂O₂.
| Catalysts  | Substrates | $K_m$/mM | $V_{max}/$(M/s) |
|-----------|------------|----------|-----------------|
| Ni@Co-NC  | H$_2$O$_2$ | 26.45    | 2.34*10$^{-7}$  |
|           | TMB        | 1.163    | 5.10*10$^{-7}$  |
| Co-NC     | H$_2$O$_2$ | 41.64    | 1.96*10$^{-7}$  |
|           | TMB        | 0.96     | 2.58*10$^{-7}$  |
| HRP       | H$_2$O$_2$ | 3.7      | 8.71*10$^{-8}$  |
|           | TMB        | 0.434    | 1.00*10$^{-7}$  |

Table S1. Comparison of the kinetic parameters of Ni@Co-NC, Co-NC, and HRP.
Figure S10. CLSM images and corresponding colocalization analysis of FITC-labeled MRSA were in-situ recorded after 5, 15, and 30 min of incubation with R18-labeled Ni@Co-NC.
Figure S11. (a) SEM images of MRSA after treatment with an identical concentration of Ni@ZIF67-C and Ni@Co-NC for 30 min. The uncoupled bionanocatalysts were removed by centrifugation at 3000 rpm three times. (b) Numbers of bionanocatalysts that bind with bacteria, which were estimated from 7 SEM images. All experimental data are displayed as the average values (mean ± SD, n = 7). Asterisks indicate significant differences (*P<0.1, **P < 0.01, ***P < 0.001).
Figure S12. Close-up (a) SEM and (b) TEM images that reveal the hooking action imposed by Ni@Co-NC.
**Figure S13.** Cryo-TEM image of MRSA after incubated with Ni@Co-NC for 30 min.

In order to prove the direct binding of the Ni@Co-NC to the bacteria, which is difficult to determine from individual projection images alone, side-by-side stereograms (stereo pairs of cryo-TEM at 8° view angle) were recorded. Scale bar: 100 nm.
Figure S14. Cryo-TEM images of the Ni@Co-NC-treated MRSA with (a) severe membrane disruption and (b) significant cytoplasm leakage. Scale bar: 100 nm. (c) SEM images of MRSA-treated by Ni@Co-NC. Scale bar: 250 nm.
Figure S15. Typical agar plate photos of MRSA after treatment with Ni@Co-NC at pH 5.5 under different concentrations and activation conditions. -2, -3, -4, -5, and -6 represent 100, 1000, 10000, 100000, and 1000000 times, respectively, of dilution for bionanocatalysts-bacterial solution before performing plate count method.
Figure S16. Typical agar plate photo of MRSA before-and-after treatment of (a) Ni@ZIF67-C and Ni@Co-NC at pH 5.5 and (b) Ni@Co-NC at pH 7.4. -3, -4, and -5 represent 1000, 10000, 100000 times, respectively, of dilution for the bionanocatalysts-bacterial solution before performing the plate count method.
Figure S17. Colony-forming unit of extended-spectrum β-lactamase-producing *Escherichia coli* before-and-after treatment with activated Ni@Co-NC.
Figure S18. 3D confocal images and corresponding orthogonal views of FITC-labeled MRSA biofilm after treatment with R18-labeled Ni@Co-NC for 30 min.
Figure S19. CCK-8 assay for HaCaT cells incubated with different concentrations of Ni@Co-NC.

The potential reason for causing slight cytotoxicity: the nanohook-equipped bionanocatalysts might cause slight cytotoxicity because the nanohooks structure can also bind to cells by hydrophobic interaction, thus resulting in slight physical damage towards cells. While it is worth mentioning that this toxicity was not permanent as demonstrated in animal experiments, and the cells will soon regrow after disinfection. Therefore, we think this slight cytotoxicity was acceptable in the practical wound infection treatment.
Figure S20. (a) Representative photos of wounds after different treatments at day 0, day 1, day 6, and day 12. (b) Wound closure after different treatments.
Figure S21. *In vivo* NIR-triggered heating images of wounds treated by Ni@Co-NC and PBS.

**The photothermal treatment condition for in vivo experiments:** according to the previous study, human skin burns partially at 55 °C when exposure time up to 70 seconds, but below this range, might only feel discomfort.\(^2\) From previous animal studies with photothermal treatment (around or even above 55 °C) as well as our animal study presented in this article, no lesion of the burn was noticed from histological analysis after treatment, indicating this 55 °C local heat will not lead to irreversible damage towards skin tissues.\(^3-5\)
Figure S22. (a) Agar plates of MRSA that taken in the wound after different treatments on day 1. (b) Corresponding MRSA colony counted from the agar plates. The asterisks indicate significant differences (P values: *P < 0.05, **P < 0.01, ***P < 0.001). Values are expressed as mean ± SD, n = 3.
Figure S23. (a) Histologic analysis of the healthy tissues and wounds treated by Ni@Co-NC+ laser and Ni@Co-NC+H₂O₂. In this experiment, H&E, Masson, and CD31 staining were used to study inflammation response, collagen deposition, and revascularization in the wound area, respectively. (b) Inflammatory infiltration fraction, (f) collagen volume fraction, and (g) CD31 expression of healthy tissue and wounds treated by Ni@Co-NC+laser and Ni@Co-NC+H₂O₂. Asterisks indicate significant differences (*P<0.1, **P < 0.01, ***P < 0.001). All data are acquired from the rabbits’ wound tissues in different groups after 12 days’ post-treatment. All values are expressed as mean ± SD, n = 3.
Figure S24. H&E staining of the major organs includes the heart, liver, spleen, lung, and kidney of healthy rabbits and rabbits after treatment of activated Ni@Co-NC.
Figure S25. (a) CD31/DAPI staining images of 3D reconstruction and corresponding maximum intensity projection (MaxIP) for wounds treated by Ni@Co-NC + laser and Ni@Co-NC+H₂O₂. (b) CD31 positive vessels number of healthy tissue, Ni@Co-NC + laser and Ni@Co-NC + H₂O₂ treated wounds.
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