Supporting Information

Single- and Dual-Band Quantum Dot-Based Nanoporous Solid-State Lasers for Gas Sensing

*Khoa Nhu Tran[1,2], Satyathiran Gunenthiran[1,2], Huong Nguyen Que Tran[1,2], Zichu Zhao[1,2], Zeyad T. Alwahabi[1], Andrew D. Abell[2,3], Cheryl Suwen Law[*1,2], and Abel Santos[*1,2]*

[1]School of Chemical Engineering, The University of Adelaide, South Australia 5005, Australia
[2]Institute for Photonics and Advanced Sensing, The University of Adelaide, South Australia 5005, Australia
[3]Department of Chemistry, The University of Adelaide, South Australia 5005, Australia

***E-Mail address:** cherylsuwen.law@adelaide ; abel.santos@adelaide.edu.au

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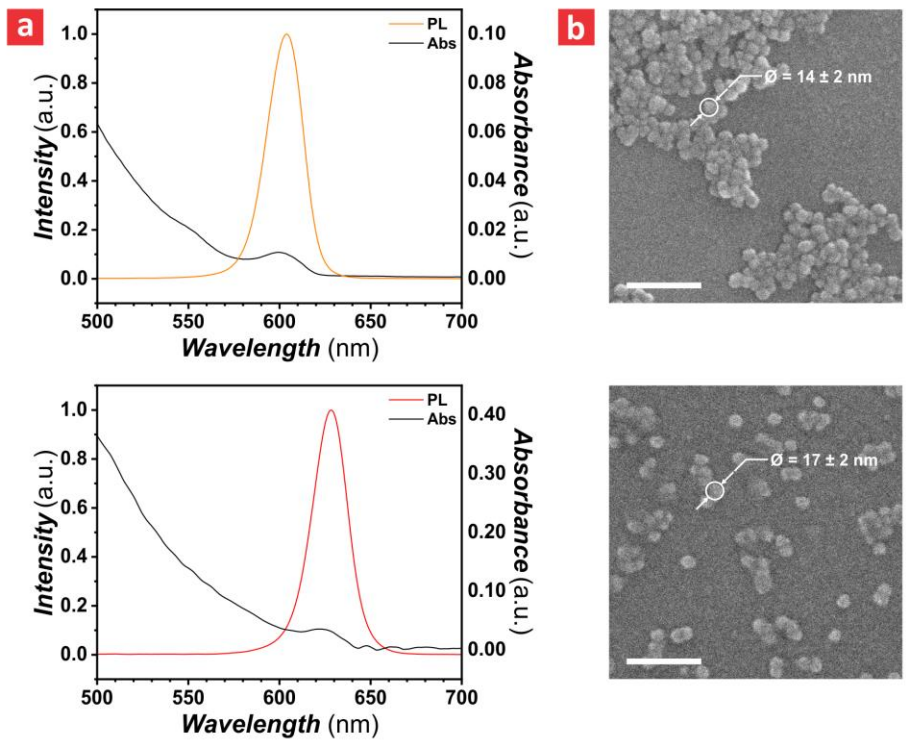

Figure S1. Properties of the core-shell type QDs used in this study. (a) Photoluminescence and absorbance spectra of colloidal QD_{604} (top) and QD_{628} (bottom) in solution. (b) FEG-SEM images of QD_{604} (top) and QD_{628} (bottom) with notes of the diameter of one QD (scale bar = 100 nm).

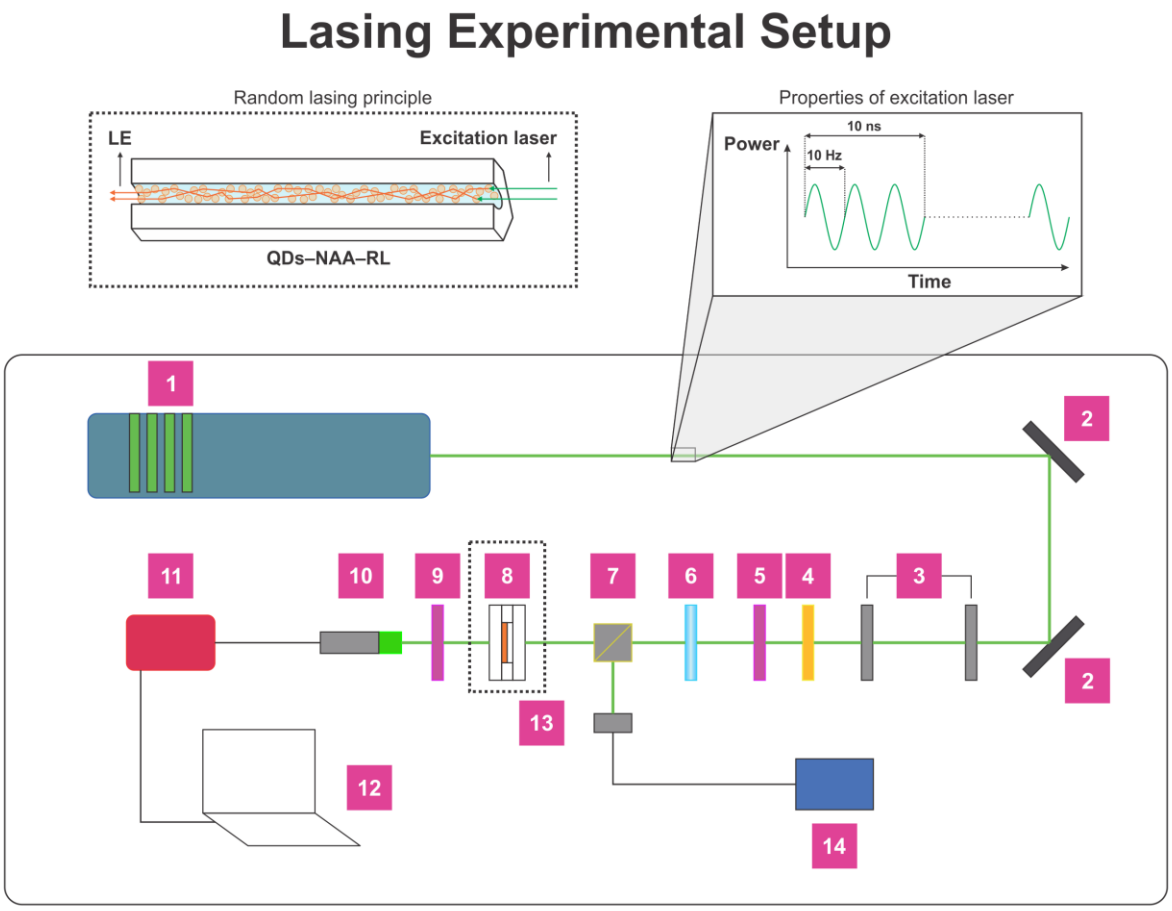

Figure S2. Optical pumping pulsed-laser setup used to characterize lasing emission from QDs–NAA–RL platforms with an optical excitation laser at 532 nm (pulse width = 10 ns, frequency = 10 Hz). The components in the setup as numbered are: (1) Nd^{3+}:yttrium aluminum garnet (YAG) pulsed laser, (2) mirrors, (3) iris system, (4) half-wave ($\lambda/2$) plate, (5) polarizer, (6) lens, (7) beam splitter, (8) sampler holder/gas sensing cell, (9) polarizer, (10) collection lens (with 532 nm optical filter), (11) optical fiber spectrometer, (12) computer, (13) power sensor, (14) power meter. NB: details of the optical components are included in **Table S1**.

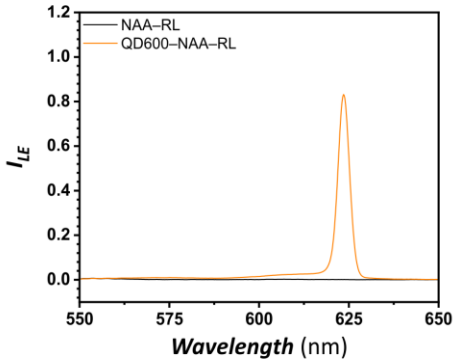

Figure S3. Emission spectra of NAA–RL before and after deposited with QD_{604} acquired with lasing setup at E_{Ex} = 6.00 mW·cm^{-2}.

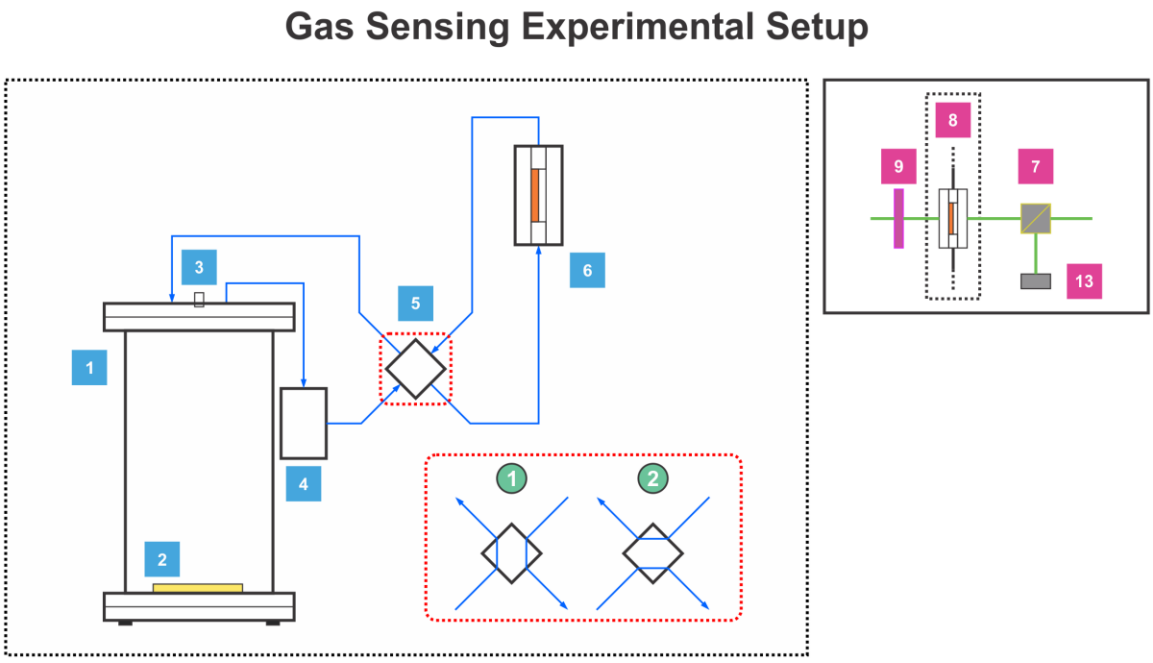

Figure S4. Custom-engineered experiment setup used in gas sensing performance assessments of QDs–NAA–RL systems. The components in the setup as numbered are: (1) gas preparation chamber, (2) electric heater, (3) concentrated gas fill port, (4) circulation pump, (5) 4-way valve (with 2 positions), (6) custom-made acrylic gas sensing cell/sample housing.

Note. Description of the gas sensing setup and experimental procedure used in performance assessment of QDs–NAA–RLs.

- Setup description:

A custom-engineered experimental setup was used to evaluate the gas sensing performance of the sensors under a dynamic flow of testing gases. In this setup, the analyte gas with the desired concentration was prepared in a sealed gas dilution chamber (1) by injecting a specific volume of concentrated gas through the fill port (3), allowing it to dilute with the air inside the chamber. A circulation pump (4) and a 4-way valve (5), set to position 1, mixed the freshly injected gas to achieve homogeneity at the desired concentration. Once mixed, the 4-way valve (5) was switched to position 2 to direct the prepared gas into a specially designed acrylic flow cell (6), where the sensors were tested. The tests were conducted under dynamic flow conditions at 25°C with a fixed flow rate of 12 $L \cdot min^{-1}$. After each test, the chamber could be vented through the fill port (3) to evacuate the previous contents and avoid contamination.

The concentration of the gas mixture was controlled by adjusting the volume of concentrated gas injected into the preparation chamber for dilution. The final concentration (in ppmv) was estimated based on the volume ratio between the injected concentrated gas and the air volume inside the chamber (~12 L).

The optical response of the sensors was obtained in optical transmission configuration using the lasing setup described in **Figure S2**. The gas sensing setup was directly connected to the sensing cell (6), which was integrated into the lasing setup. The light source was positioned normally to the top surface (front) of the sample (with an illumination spot of 6 mm in diameter), and the transmitted light was collected from the bottom (back) of the sample. The optical transmission spectra of the QD–NAA–RL sensors were acquired in real time, and Gaussian fittings were applied to the characteristic lasing bands using MATLAB (MathWorks). All experiments were conducted on an optical table to minimize interference from vibrations.

- Experimental procedure:

The sensing performance of single-QDs–NAA–RL sensors was evaluated by exposing them to a range of NO_2 gas concentrations, from 10 to 40 ppmv. Before each experiment, the sensors were exposed to a flow of clean air for 5 minutes to establish a stable baseline. Subsequently, the sensors were continuously exposed to increasing concentrations of NO_2, with increments of 10 ppmv. After the exposure, the sensors were removed from the flow cell, placed under vacuum for recovery, and re-measured after 24 hours to assess the recovery of the lasing signals.

For discriminative gas sensing, the dual-QDs–NAA–RL sensors were assessed using NO_2 gas and ETOH vapor, following a similar procedure as the single-QDs sensors. The concentration of each gas was controlled from 10 to 40 ppmv, in 10 ppmv steps. Following exposure, the sensors were again placed under vacuum for recovery and re-measured after 24 hours to evaluate the restoration of the lasing signals.

The optical transmission signal was collected in real time and processed using MATLAB for analysis. Key optical features of the lasing bands (including λ_{LE}, $FWHM_{LE}$, I_{LE}, Q_{LE}, and G_{LE}) were determined by applying Gaussian fitting, with each measurement recorded with a timestamp. The lasing quenching kinetics were analyzed by applying exponential decay fitting to the plot of lasing gain versus analyte concentration. This method was repeated for all lasing bands exhibited by the QDs–NAA–RL sensors.

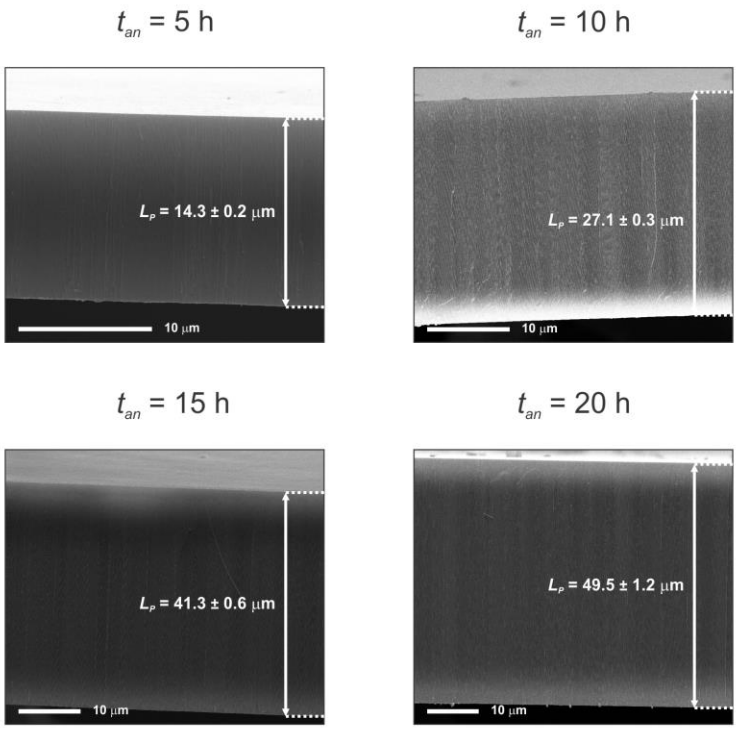

Figure S5. Structural analysis via FEG-SEM images to determine the nanopore length L_P of NAA–RL samples fabricated with different anodization time of the second step, i.e., t_{an} = 5, 10, 15, and 20 h.

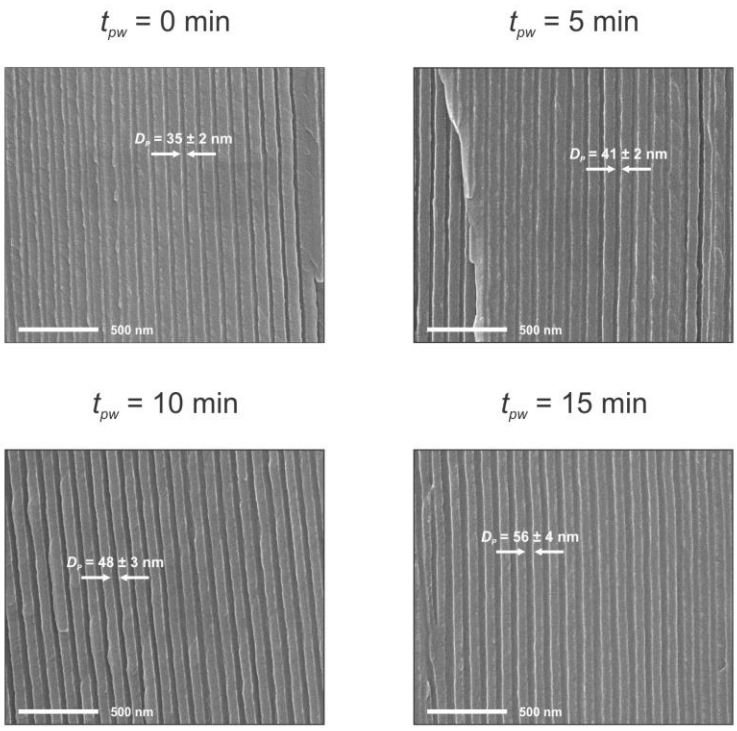

Figure S6. Structural analysis via FEG-SEM images to determine the nanopore diameter D_P of NAA–RL samples being treated with pore-widening process for t_{pw} = 0, 5, 10, and 15 min. (NB: samples presented in this analysis were fabricated with t_{an} = 20 h)

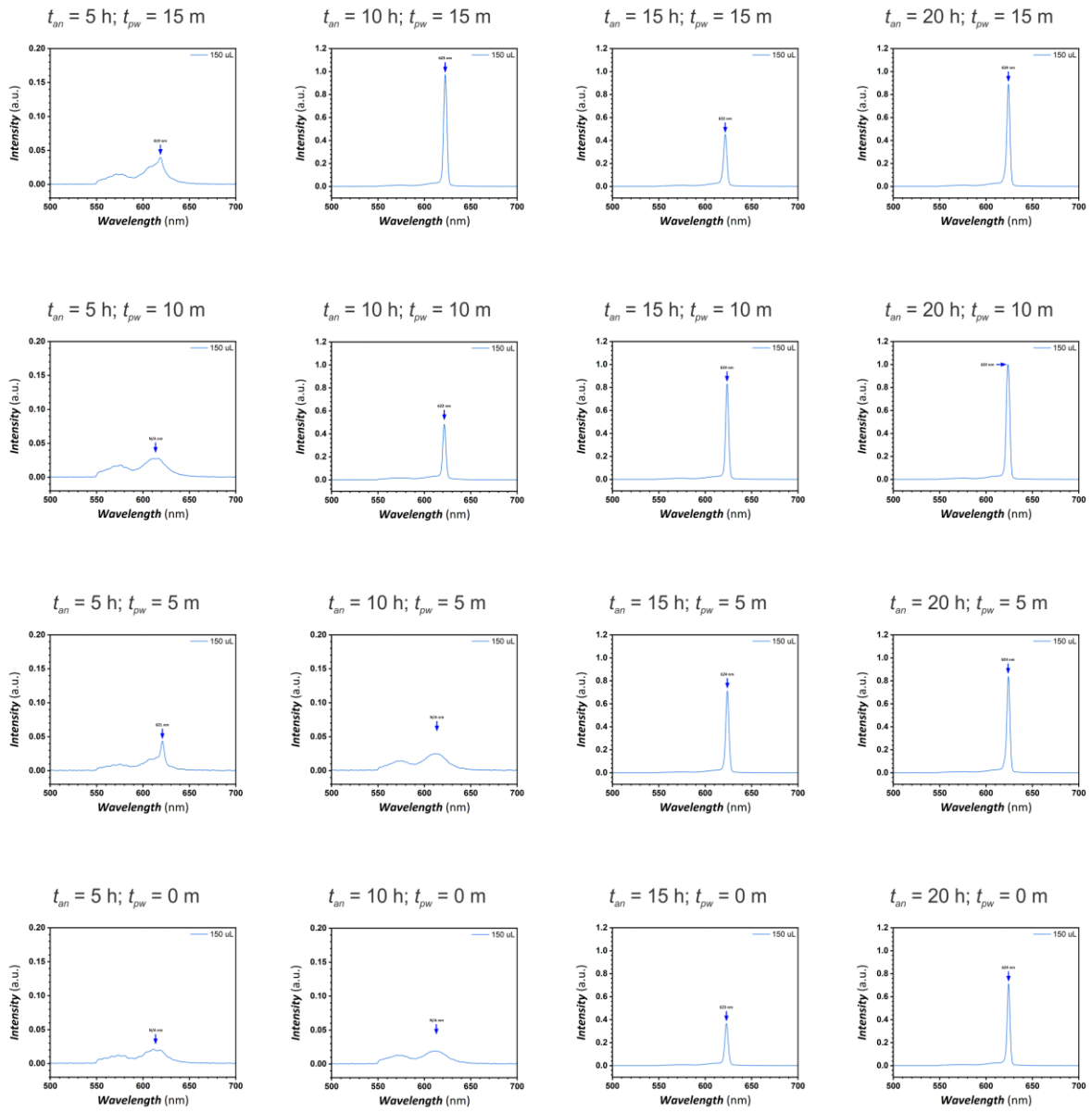

Figure S7. Lasing emission spectra of all samples studied in the *Structural Optimization of Lasing in QDs–NAA–RL Platforms* section in our manuscript. All samples were fabricated with the conditions reported in **Figure S5** and **Figure S6**, and were prepared with QD_{604}. Lasing experiments were conducted using setup presented in **Figure S2** at E_{Ex} = 6.00 $mW \cdot cm^{-2}$.

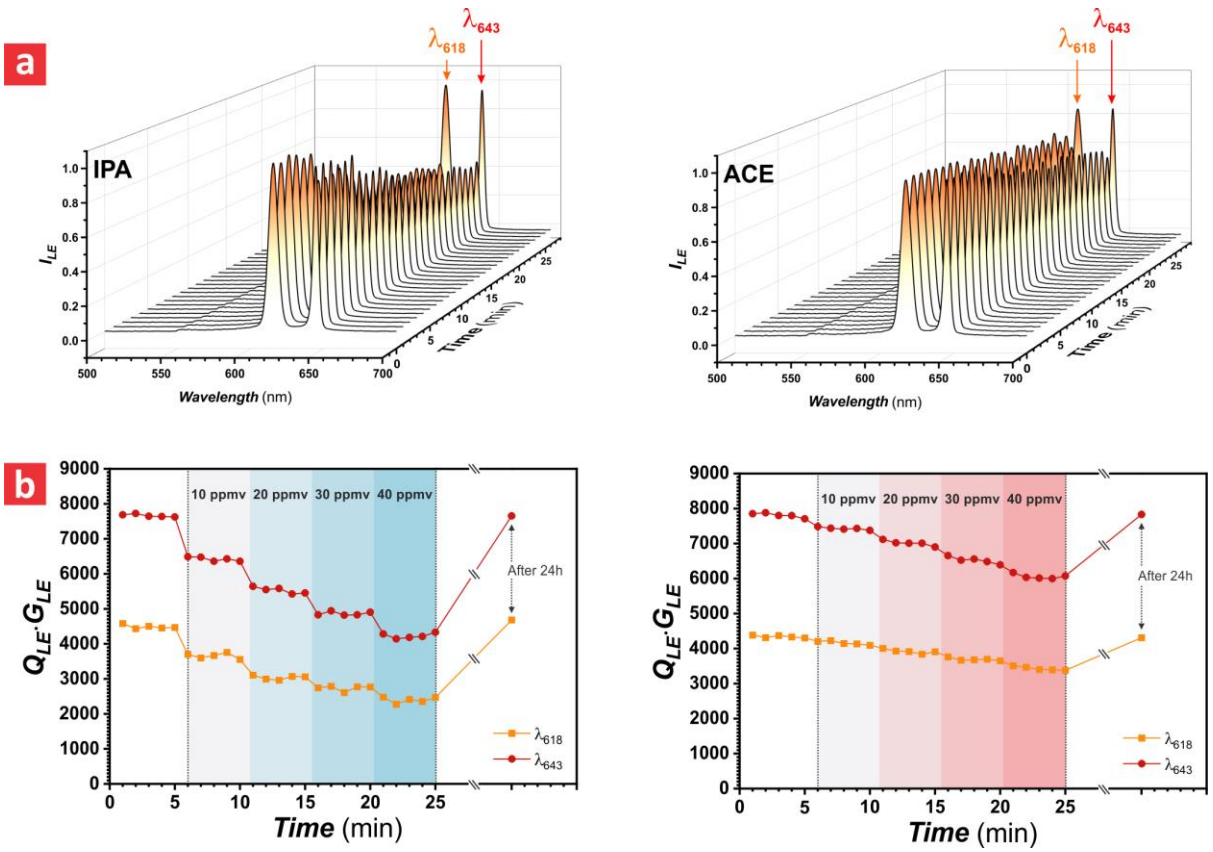

Figure S8. Gas sensing performance of the dual-$QD_{604/628}$–NAA–RL system under exposure to isopropanol (IPA) and acetone (ACE). (a and b) Lasing emission spectra of the $QD_{604/628}$–NAA–RL sensor during exposure to IPA (left) and ACE (right), showing the quenching of lasing bands at 618 nm (denoted λ_{618}) and 643 nm (denoted λ_{643}) as the gas concentration increased from 10 to 40 ppmv. (b) Real-time quantification of Q_{LE}·G_{LE} change for both lasing bands during exposure to IPA (left) and ACE (right), followed by a 24 h-recovery.

Table S1. List of optical components used in our setup shown in Figure S2. All components were acquired from Thorlabs.

Component	Description	Specifications
1	Nd3+:YAG pulsed laser	Surelite II Continuum, λ_{Ex} = 532 nm, τ_P = 8 ns, f = 10 Hz
2	Nd:YAG Laser Line Mirrors	NB1–K13 - Ø1", 532 nm and 1064 nm, 0° to 45° AOI (2 units)
3	Post-Mountable Iris Diaphragms	ID20/M - Mounted Standard Iris, Ø20.0 mm Max. Aperture, TR75/M Post (2 units)
4	Mounted Zero-Order Half-Wave Plates	WPH05M-532 - Ø1/2" Zero-Order Half-Wave Plate, Ø1" Mount, 532 nm (and PRM1 Rotation Mount)
5	1st Glan-Laser Calcite Polarizer	GL10-A, Ø10 mm CA, AR Coating: 350 - 700 nm (and SM1PM10 Mount on a PRM1 Rotation Mount)
6	UV Fused Silica Bi-Convex Spherical Lenses	LB4096-AB, Ø1" Bi-Convex Lens, AR Coating: 400 - 1100 nm, f = 50 mm
7	Non-Polarizing Beamsplitter Cube	BS037 - 10:90 (R:T), 400 - 700 nm, dimensions: 10x10x10 mm
8		
9	2nd Glan-Laser Calcite Polarizer	GL10-A, Ø10 mm CA, AR Coating: 350 - 700 nm (and SM1PM10 Mount on a PRM1 Rotation Mount)
10	SMA Collimation Package/Collection Lens + Longpass Filter	F810SMA-543 - 543 nm SMA Collimation Package, NA = 0.26, f = 34.74 mm + FELH0550 - Ø25.0 mm Longpass Filter, Cut-On Wavelength: 550 nm
11	Ocean Optics Optical Fiber Spectrometer	USB4000–XR1–ES, Ocean Optics Integration time = 10 ms, Average measurements = 10
12	Computer	-
13	Pyroelectric Energy Sensor, Black Coating	ES120C, 0.185 - 25 µm, 500 mJ, Ø20 mm, 30 Hz
14	Digital Power & Energy Console, Si Sensor	PM121D, 400 nm -1100 nm, 500 nW - 500 mW