Nano-photonic Biomolecular Sensors with Passive Molecule Trapping Functionality

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Introduction

- Molecules have their fingerprint vibrational absorption peaks. These vibrations have relatively small dipole moments (which usually are not even in the nm scale), and therefore interacts with light weakly[1].
- Nanophotonic resonators can confine light in the near field significantly below the wavelength scale of light in free space, and can even reach the nm scale[2].
- Confined electric fields of light in nanophotonic resonators can enhance the molecular vibrational absorption, and such an enhancement is proportional to near field intensity[3].
- Trapping more molecules into areas with high field intensity will greatly improve the sensitivity of such optical sensors[4].
- Here we experimentally demonstrate molecular sensors with passive and straightforward molecule trapping functionality.[5]

Device structure

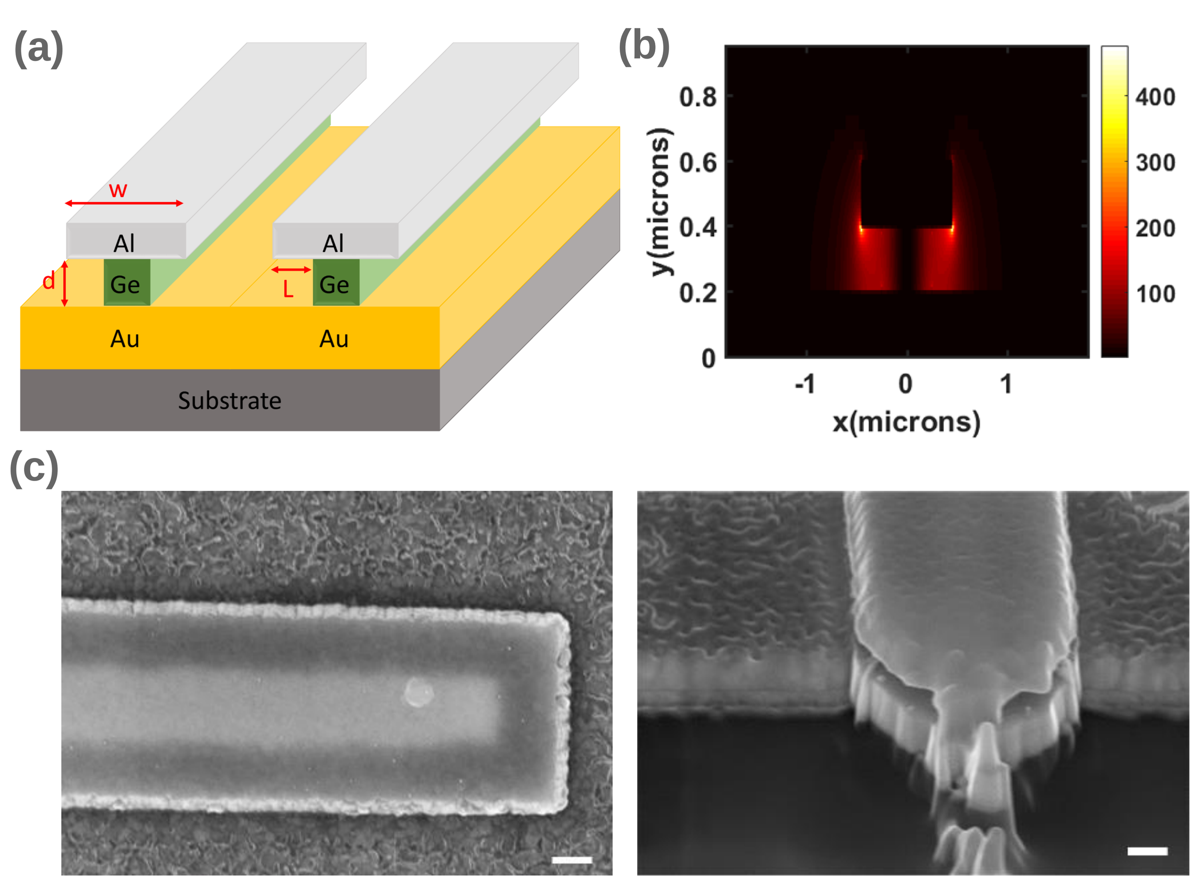

Figure 1. structure of the designed device (a). Schematic of a unit sensor structure; (b). Simulated electric field intensity distribution; (c). SEM images of fabricated devices. Scale bar is 400nm.

- Metal-insulator-metal resonator structure
- Germanium layer is etched sideways to create the nanotrenches for trapping analyte molecules
- Simulated results show high near-field enhancement in the nanotreches

Molecule trapping function

To confirm whether molecules in a solution can be trapped in the nanotrenches as the solvent evaporates, we also fabricate structures with the Al stripes replaced by photoresist (PR) stripes for easy optical observation and use fluorescent dye molecules for the test.

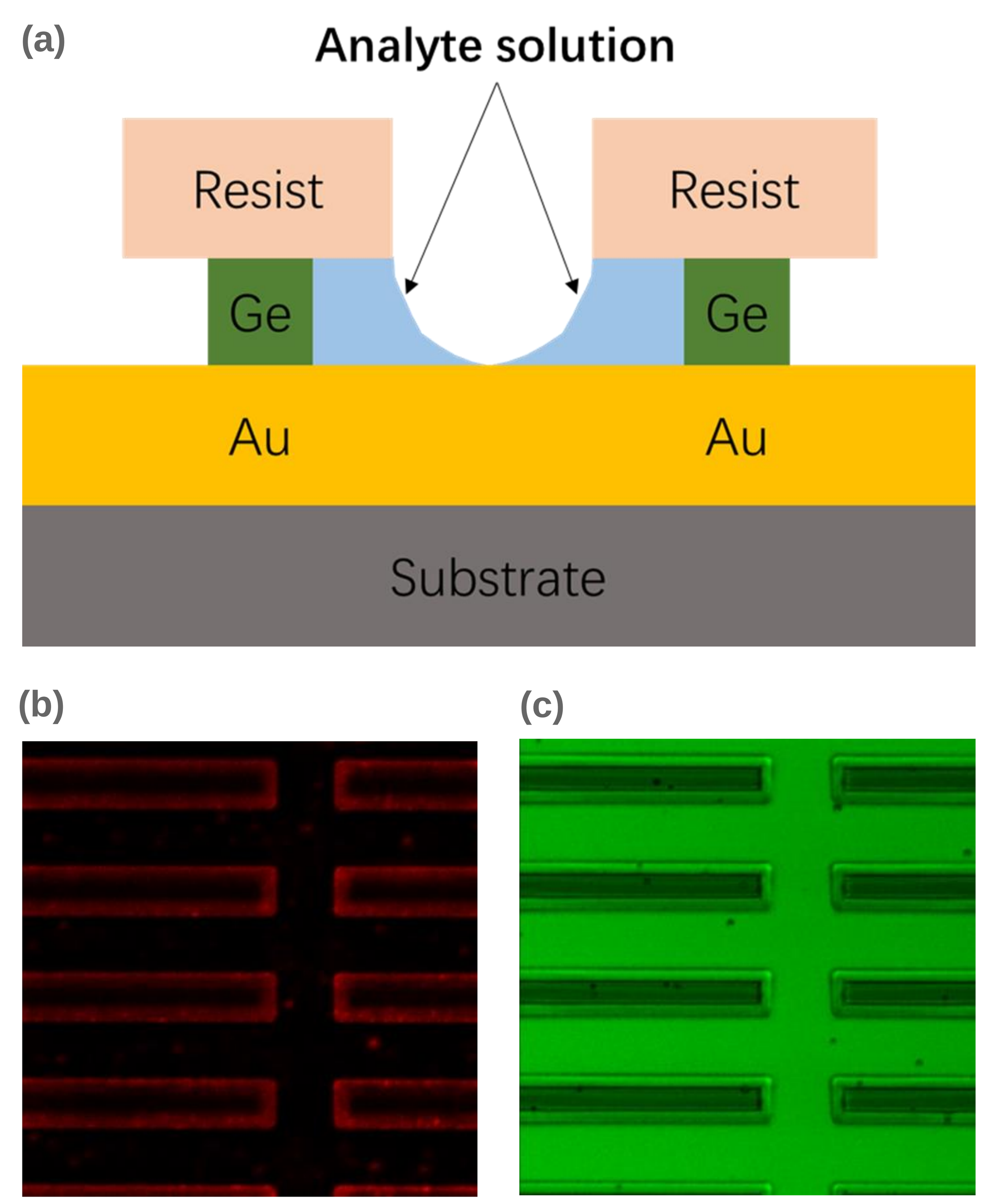

Figure 2. fluorescent dyes trapping (a). Scheme diagram of structure for trapping fluorescent dyes; (b)confocal fluorescent images at wavelength 707nm; (c) confocal reference images at wavelength 505nm.

- Water-based liposomes solution containing Cyanine 5.5 fluorescent dye is dip-coated on device chip and dried.
- The intensity of excited fluorescence is high near the edges of the PR stripes, which matches the patterns of the transparent trenches in the reference scattering image.
- Intensity of excited fluorescence is low in areas outside the nanotrenches.
- The fluorescence measurement shows that nanotrenches in our designed structures can effectively trap molecules in a drying solution.

Sensing results

For proof-of-concept demonstration of our biomolecular sensor performance, we use amino acid L-Proline as the analyte which has multiple absorption lines in the spectral range of 1000cm^{-1} to 1700cm^{-1}.

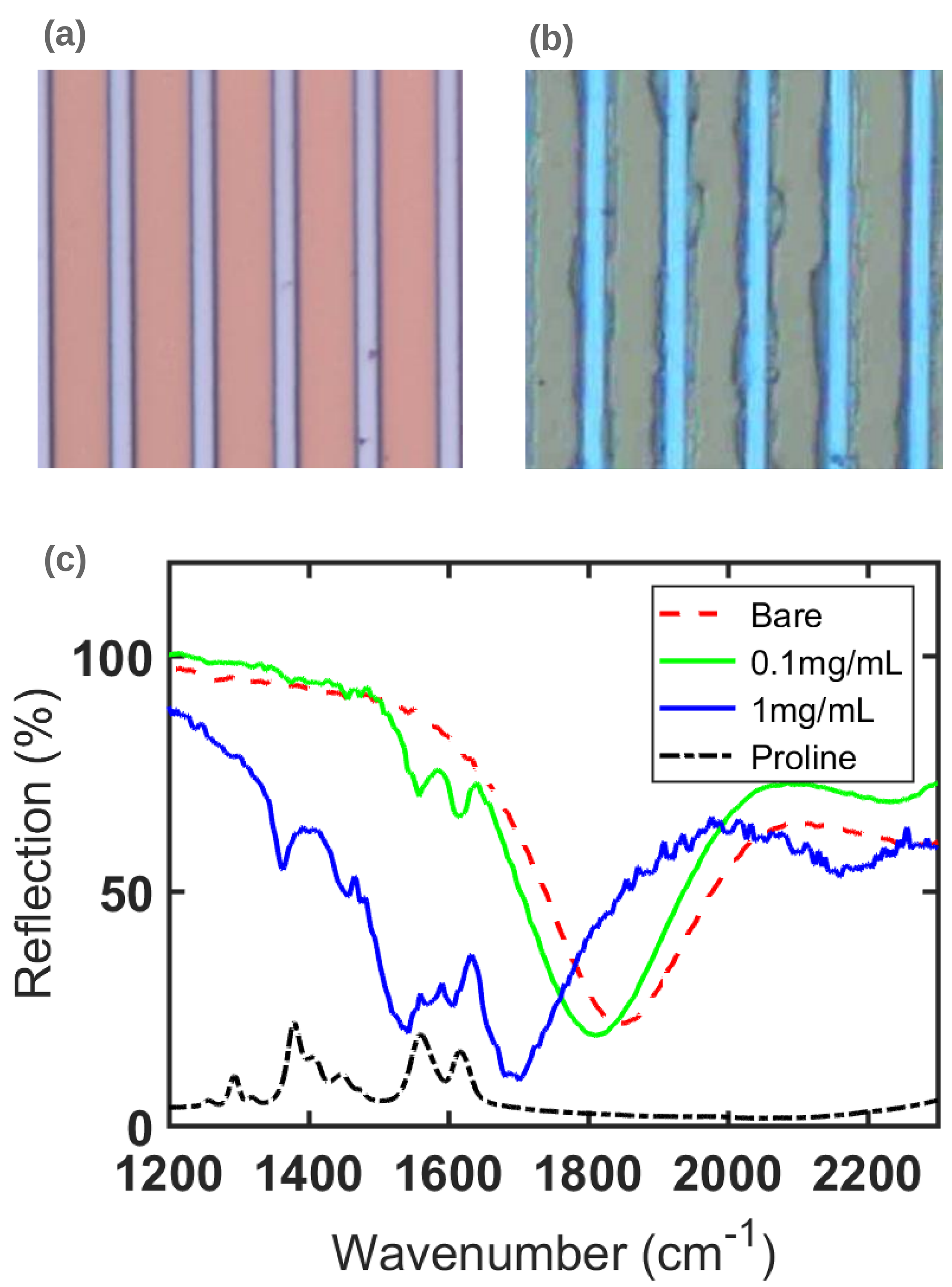

Figure 3. FTIR measurement for sensing L-Proline molecules. (a)&(b) Optical images of the device (a) before and (b) after applying ~5uL ethanol-based L-Proline solution. (c) Measured reflection spectra of devices after applying L-Proline solutions of the specified concentrations.

- 5μL ethanol-based L-Proline solution is added to the device surface which quickly spreads over the entire chip surface (~5mm by 5mm) and dries.
- Top-view optical images of a device shows that L-Proline is mostly distributed near the edges of the Al stripes.
- L-Proline absorption lines in the region between 1300cm^{-1} and 1700cm^{-1} are clearly observed, with the strongest signal obtained with the device exhibiting the most matching resonance frequency.

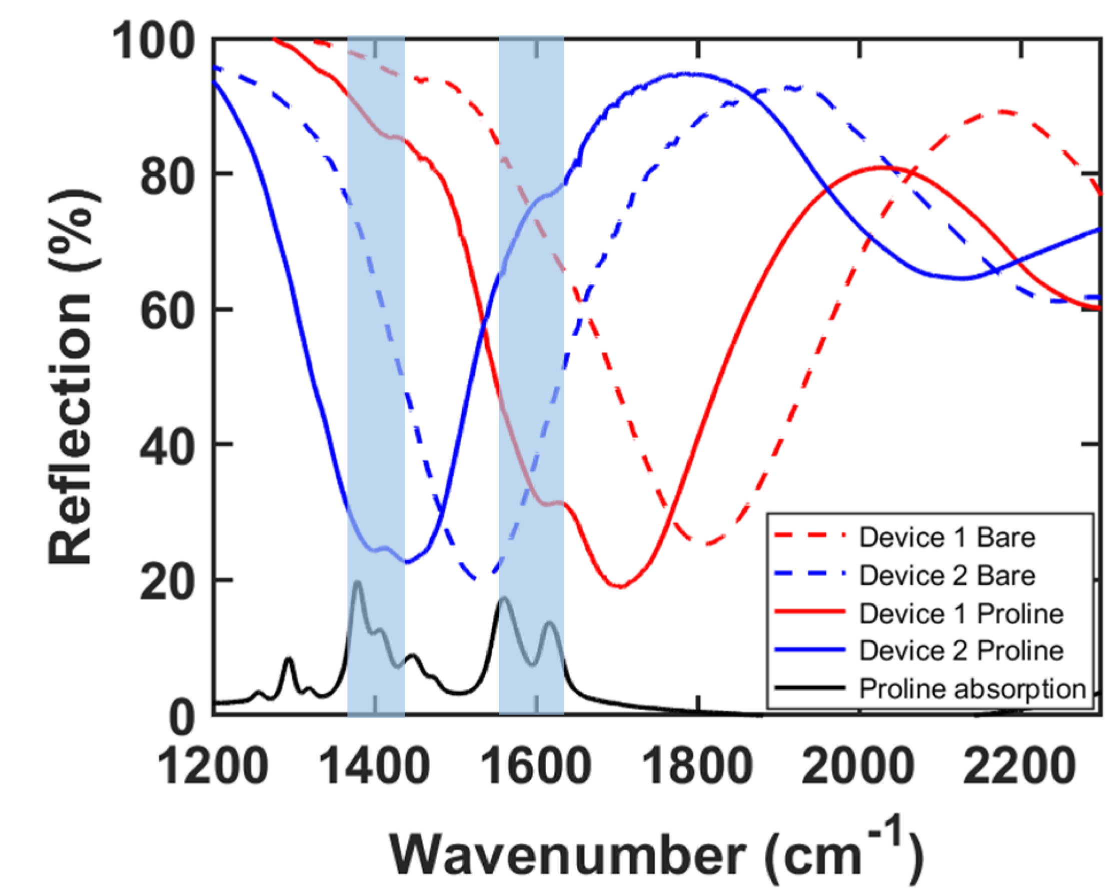

Figure 4. FTIR measurement for sensing L-Proline molecules in water-based solutions.

- 1μL 10μg/mL water based Proline solution is added to the device surface and dries.
- L-Proline absorption lines in the region 1400cm^{-1} and 1600cm^{-1} are also clearly observed.
- The sensitivity is significantly higher due to less spreading of water-based solution on the device surface.

Conclusion

- Fluorescence dye measurement shows that nanotrenches in our sensor structure can trap molecules effectively.
- Our designed sensor can trap L-Proline into the nanotrenches and the high field enhancement in nanotrenches enhance the vibrational absorption of L-Proline molecules.
- Our sensors can resolve the absorption lines of L-Proline molecules contained in 1μL solution with 10μg/mL concentration.

Acknowledgment

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References

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