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EPFL scientists build first self-illuminating biosensor

Engineers have harnessed quantum physics to detect the presence of biomolecules without the need for an external light source, overcoming a significant obstacle to the use of optical biosensors in healthcare and environmental monitoring settings.

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Optical biosensors use light waves as a probe to detect molecules, and are essential for precise medical diagnostics, personalized medicine, and environmental monitoring. Their performance is dramatically enhanced if they can focus light waves down to the nanometer scale - small enough to detect proteins or amino acids, for example - using nanophotonic structures that ?squeeze' light at the surface of a tiny chip. But the generation and detection of light for these nanophotonic biosensors requires bulky, expensive equipment that greatly limits their use in rapid diagnostics or point-of-care settings.

So, how do you make a light-based biosensor without an external light source? The answer is: with quantum physics. By harnessing a quantum phenomenon called inelastic electron tunneling, researchers in the Bionanophotonic Systems Laboratory in EPFL's School of Engineering have created a biosensor that requires only a steady flow of electrons - in the form of an applied electrical voltage - to illuminate and detect molecules at the same time.

ï¿½If you think of an electron as a wave, rather than a particle, that wave has a certain l w probability of ?tunneling' to the other side of an extremely thin insulating barrier whi e emitting a photon of light. What we have done is create a nanostructure that both forms pa t of this insulating barrier and increases the probability that light emission will take place,i ?½ explains Bionanophotonic Systems Lab researcher Mikhail Masha

Trillionth-of-a-gram detection

In short, the design of the team's nanostructure creates just the right conditions for an electron passing upward through it to cross a barrier of aluminum oxide and arrive at an ultrathin layer of gold. In the process, the electron transfers some of its energy to a collective excitation called a plasmon, which then emits a photon. Their design ensures that the intensity and spectrum of this light changes in response to contact with biomolecules, resulting in a powerful method for extremely sensitive, real-time, label-free detection.

ï¿½Tests showed that our self-illuminating biosensor can detect amino acids and polymers

t picogram concentrations - that's one-trillionth of a gram - rivaling the most advanced senso
s available today,ï¿½ says Bionanophotonic Systems Laboratory head Hatice Al
ug. The work has been published in Nature Photonics in collaboration with ETH Zurich, Yonsei University (Korea) and **ICFO and ICREA Prof. Javier Garcia de Abajo**. According to the Professor: "This is a solid step toward the integration of plasmonic devices by eliminating the need for external light."

A dual-purpose metasurface

At the heart of the team's innovation is a dual functionality: their nanostructure's gold layer is a metasurface, meaning it exhibits special properties that create the conditions for quantum tunneling, and control the resulting light emission. This control is made possible thanks to the metasurface's arrangement into a mesh of gold nanowires, which act as ?nanoantennas' to concentrate the light at the nanometer volumes required to detect biomolecules efficiently.

ï¿½Inelastic electron tunneling is a very low-probability process, but if you have
a low-probability process occurring uniformly over a very large area, you can still colle
t enough photons. This is where we have focused our optimization, and it turns out to be
a very promising new strategy for biosensing,ï¿½ says former Bionanophotonic Systems
Lab researcher and first author Jihye Lee, now an engineer at Samsung Electron
cs. In addition to being compact and sensitive, the team's quantum platform, fabricate
at EPFL's Center of MicroNanoTechnology, is scalable and compatible with sensor manufacturing methods. Less than a square millimeter of active area required for sensing, creating an exciting possibility for handheld biosensors, in contrast to current table-top setups.

ï¿½Our work delivers a fully integrated sensor that combines light generation and detecti
n on a single chip. With potential applications ranging from point-of-care diagnostics
o detecting environmental contaminants, this technology represents a new frontier
n high-performance sensing systems,ï¿½ summarizes Bionanophotonic Systems Lab resear
her Ivan Si

Reference:

Jihye Lee, et. al., Plasmonic biosensor enabled by resonant quantum tunneling, Nature Photonics (2025).

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