Science AMA Series: I am Lan Yang, an electrical engineering professor at Washington University in St. Louis. My research is in nanophotonics, high-quality optical microresonators, and finding better ways to detect nanoparticles. AMA!

Lan-Yang [1] and r/Science AMAs[1]

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Abstract

Hi reddit! Thank you so much for your excellent questions today. I'm sorry I didn't get to answer all of them, but I will try to come back later today to answer those I missed. I hope it was as enjoyable for you as it was for me. I am Lan Yang, an electrical engineering professor at Washington University in St. Louis. My interests are in transforming the research discoveries in fundamental science to technologies that could benefit the society and improve the quality of life. My research has centered around high-quality optical microresonators, which could significantly enhance light-matter interactions and therefore triggers many interesting physics. The research in my group falls in two categories: one is about fundamental understanding of interesting physics in high-quality optical resonators, and the other is to seek applications enabled by such a structure, such as sensing — particularly, nanoscale sensing — which have a direct impact on broad applications from environmental monitoring to early disease diagnosis and health care. A few years ago, we developed an on-chip sensor that could detect and measure the size of individual nanoparticles. Recently, my group has made some progress in unconventional control of light flow in optical structures by exploiting special features associated with parity-time-symmetry and exceptional points. It's not surprising that fundamental science doesn't show a direct connection to applications. But when opportunities come, it's natural for us to combine these two directions. This time, we are developing a new sensing technology by using a special feature associated with a resonator when it's operated around exceptional points.

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LAN-YANG R/SCIENCE

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My research has centered around high-quality optical microresonators, which could significantly enhance light-matter interactions and therefore triggers many interesting physics. The research in my group falls in two categories: one is about fundamental understanding of interesting physics in high-quality optical resonators, and the other is to seek applications enabled by such a structure, such as sensing — particularly, nanoscale sensing — which have a direct impact on broad applications from environmental monitoring to early disease diagnosis and health care.
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How can the sensors know what kind of particles they sense? Do they match the incoming data in a database, or is there some sort of categorizing algorithm that can tell the type of particles apart?

false_anemone

This is a good question because it echoes with our long-term goal for our resonator sensors. When light propagates in an optical resonator with circular boundary, it could propagate in either clockwise (cw) and counterclockwise (ccw) direction. That being said, an optical mode in a circular micro-resonator possesses a natural two-fold degeneracy due to two possible propagation directions, cw) and ccw. Such two degenerated modes share the same resonant frequency and field distributions but propagate in opposite directions. When a subwavelength scatterer enters the light field of the resonator, it scatters light which induces a coupling between the two counter propagating modes and lift their degeneracy, which is manifested as splitting of a sing resonance to a doublet structure. Because the spectral feature, such as the spectral separate and shape of the two split modes is determined by the scattering induced by the particle, we could derive the information, such as the

optical microresonators, and finding better ways to detect nanoparticles. AMA!, *The Winnower* 4:e150487.75048 , 2017 , DOI: 10.15200/winn.150487.75048

polarizability which is relevant to the particle size and refractive index, by analyzing the transmission spectra of the optical resonator. More information can be found in our first paper on this topic ("On-chip single nanoparticle detection and sizing by mode splitting in an ultrahigh-Q microresonator", https://www.nature.com/nphoton/journal/v4/n1/full/nphoton.2009.237.html).

For the time being, we have demonstrated detection and size measurement of single nanoparticles using the mode-splitting technique. We haven't fully utilized the information rendered by mode-splitting spectra yet. For example, we could also get the absorption spectra of the materials from the mode-splitting spectra. By building a database and developing some algorithms, we could compare the collected mode-splitting spectra with the information in the database to identify the particles. It will be similar to what researchers have done for the Fourier-transform infrared spectroscopy (FTIR).

Thank you for doing this AMA!

Can you give some examples of what kinds of nanoparticles you are interested in sensing, and how that relates to biomedical applications? Are you sensing engineered nanoparticles that are introduced into a biological system and then attach to biological molecules, or are you sensing biological compounds themselves?

Sorry if these questions are overly simple, this is an unfamiliar area for me!

neurobeegirl

This is an important question because it's related to the motivation and significance of our research:-) Nanoparticle sensors have a broad range of applications from medical research, pharmaceutical industries, early disease diagnosis and environmental monitoring, just to name a few. I am particularly interested in nanoparticles relevant to human health, such as environmental monitoring and biosensing.

For example, we are concerned about fine particulate matter (PM2.5), which could travel to the lungs causing such health effects such as coughing, asthma and even heart disease. A portable sensor that could give us specific information of the nanoparticles in the environments could help us develop relevant strategies to deal with them.

We could also use the sensor to study the engineered nanoparticle that will be designed and tailored for medical treatment in a biological system. For example, by using our particle sensor to monitor the changes in the absorption feature and refractive index of a single nanoparticle with a specific size, we could analyze the releasing profiles of drugs encapsulated in the nanoparticles that will be injected in biological system and understand how the particle size, composition, and shape affects the drug releasing profiles. The single nanoparticle resolution helps us collect information that would have been smeared in an ensemble measurement.

We could also functionalize the particle sensors with specific chemicals to detect biological compounds. We could borrow the protocols that have been developed for ELISA (enzyme-linked immunosorbent assay) to detect specific antigens. The sensitivity of the resonator based sensor will be much higher than an ELISA system which relies on the detection of fluorescent signals.

What kind of qualifications would someone need to get into nanophotonics? (Years of schooling, degree, etc)

BabyFossaMerchant

Photonics is a multidisciplinary research field involving material science, nanofabrication, physics, engineering, and physics, etc. In my opinion, once you get college training in physics, chemistry or engineering, you are ready to enter this field.

Would you say more about the implications of your work in Physics. Most of the questions concern practical applications (which interest me too) but I'm wondering if there are results you look for based on prior work of theoretical physicists and/or are there results that pop up that lead you to new general rather than specific insights? Thank you.

mrbobdobalino

More than happy to answer this question☺ Physics has been a fascinating subject to me. Here are two examples showing interesting demo from my group starting from a prior work of theoretical physicists:

The first example is our recent work on exceptional points enhanced sensing. In 2014, Jan Wiersig of the University of Magdeburg in Germany proposed that the performance of resonator based sensor could be improved if it is operated at an exceptional point, at which the eigenvalues and eigenstates of the system coalesce (https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.112.203901). We collaborated with him and demonstrated the square-root dependence of the mode-splitting sensing signal on the perturbation magnitude (https://www.nature.com/nature/journal/v548/n7666/full/nature23281.html). This work provides a new sensing technology especially for the detection of nanoscale objects which are challenging for most optical sensors.

Another example is our research on parity-time-symmetric photonics. Starting as an abstract concept with remarkable mathematical properties in the context of quantum theory (https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.80.5243), recently parity-time symmetry (PT-symmetry) has been recognized as a significant scheme for technological breakthroughs in the “real” world. By merging PT-symmetry in high-quality on-chip optical resonators, my group demonstrated a PT-symmetric resonator system and also reported its application for nonreciprocal light transport on chip, i.e., an all-optical analog of an electronic diode that allows current flow in one direction (https://www.nature.com/nphys/journal/v10/n5/full/nphys2927.html). This study lays the groundwork for exploiting PT-symmetric phenomena to develop a new generation of synthetic optical systems enabling unconventional and advanced functionalities for on-chip manipulation and control of light flow.

Yes, hello there:

Can you please explain what your introduction *means*?

That's my question.

Explain Like I'm Stupid.

FreeBased1

It’s my pleasure to explain my research. As said in my introduction, my research has been centering around high-quality optical resonators. So what is an optical resonator? It’s a physical structure in which light could be trapped. Think of two facing mirrors between which light is bounced back and forth, in an ideal case, if there is no loss experienced by the trapped light, it could stay there forever. As a result, the light couldn’t escape from the resonator and keep repeating the same round trip, so it builds up on itself and consequently, the optical power inside the resonator is enhanced.

For an on-chip micro-resonator fabricated in our lab (a non-ideal case), the power enhancement could reach 10 to the 5th power. An input power of 1 milliwatt could generate up to 100 Watts of circulating power and 2.5 gigawatts/cm^2 of light intensity in the resonator. It's also worth noting that in our high-quality optical microresonator, light could travel for 10 meters before it decays. If the round trip of the photon in the resonator is 100 micrometers, the photon can interact with materials more than 10 meter/100micrometer=10^5 times. Such a 'signal build-up process' and long interaction time inside the resonator gives rise to significant signal amplification and enhance the interaction between the light and materials in the resonator dramatically. So we consider high-quality optical microresonators as an interesting platform to explore both fundamental science and some applications that benefit from enhanced light-matter interactions, such as lasing and sensing.