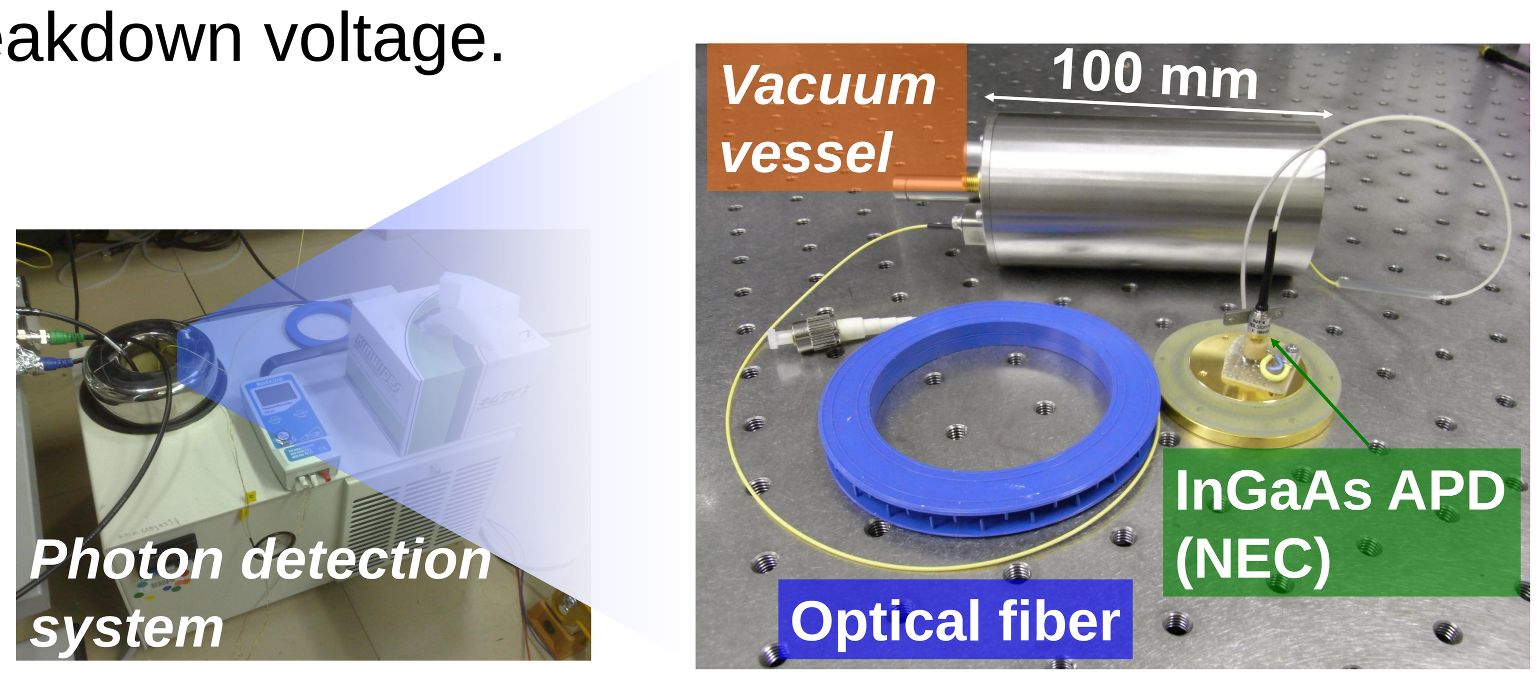
Development of Photon Detector and Demonstration of Quantum Receiver

Background: The development of a practical photon detector is very important for realizing optical quantum computation, quantum communication, and quantum cryptography. In our opinion, a photon detector based on an avalanche photodiode (APD) is a promising solution for a practical photon detector because APDs are commercially available and easy to operate. Moreover, by the addition of quantum state operations, we can realize a quantum receiver that can discriminate among the optical signals with minimal error. This technology is useful for long-haul optical communication without a conventional optical amplifier.

Photon detector for telecom wavelengths

InGaAs APDs are widely used for detecting telecom-wavelength photons. Typically, InGaAs APDs are operated in a gated mode to reduce dark counts. However, in this mode, it is necessary to know beforehand the priori timing information of input photons. Therefore, we cannot detect the photons with asynchronous arrival timing. To solve the above problem, we operated the APDs in a "sub-Geiger" mode. In this mode, we attempt to keep the bias voltage less than breakdown voltage.



We demonstrate the free-running operation of a photon detector based on InGaAs APDs. Our photon detector has a detection efficiency of 2.2% and a dark count rate of 7.9 kHz. Our system will contribute to the development of a low-cost photon detector because of its simple design and lower bias voltage than that in the gated mode operation.

Collaborated with Hokkaido Univ. and Waseda Univ.

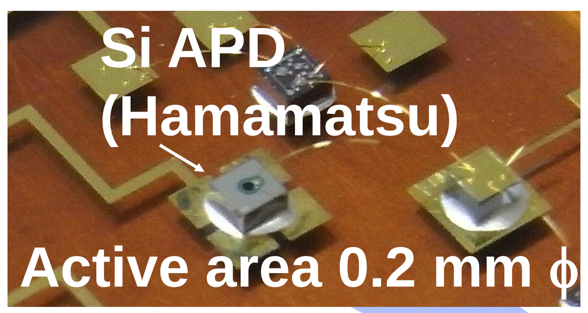
Photon detector for visible and near-infrared wavelengths

At these wavelengths, we can use high-quality non-classical sources for the proof-of-principle experiments of quantum information science. However, a photon detector based on APDs has a common detection efficiency (~70%).

We can define the detection efficiency of the photon detector as follows:

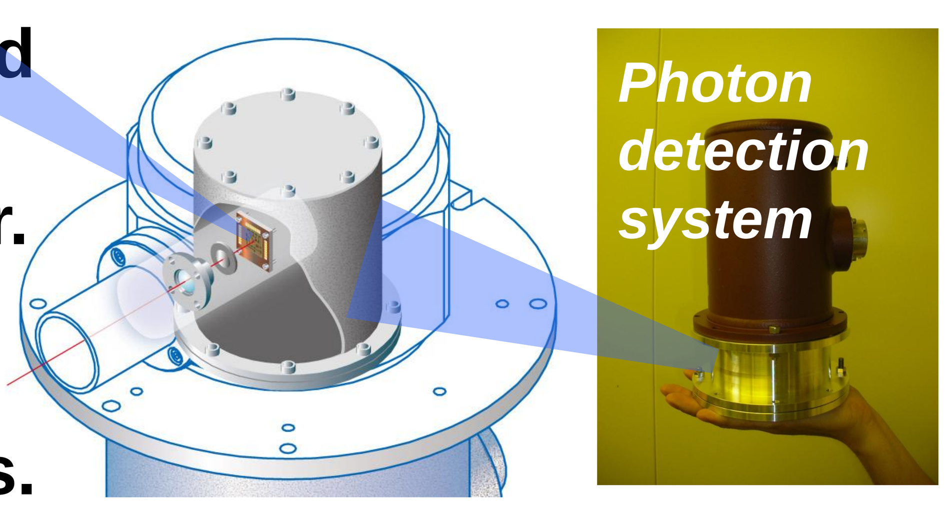
$$P_d = \eta \times P_e$$

where η and P_e are the quantum efficiency of APD and the photoelectron detection probability, respectively. To improve P_d, we should increase both η and P_e.



Si APD made by Hamamatsu Photonics has high η > 90%.

We have developed a low-noise and high-gain amplifier. Therefore, we can effectively detect the photoelectrons.

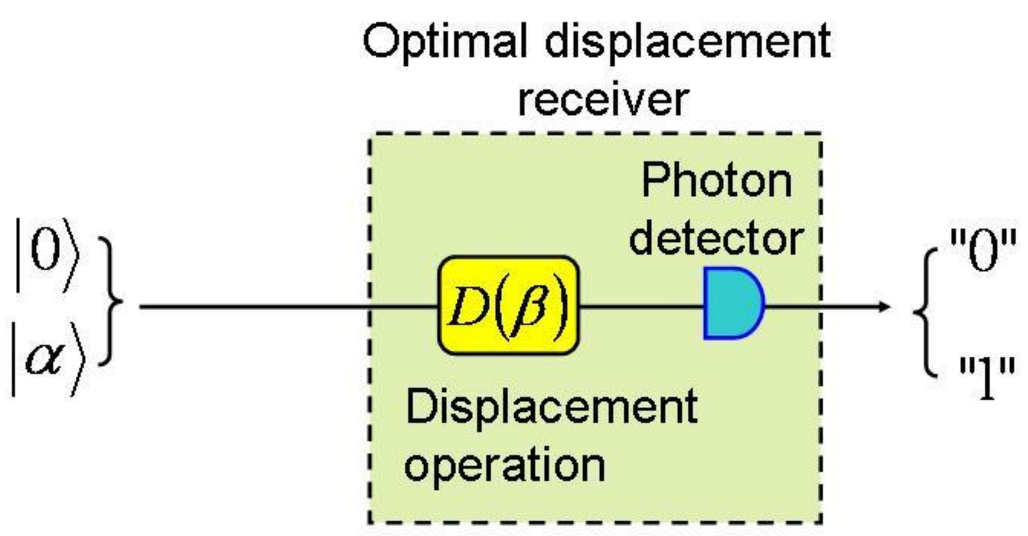


Our approach makes it possible to achieve a P_d of more than 80%.

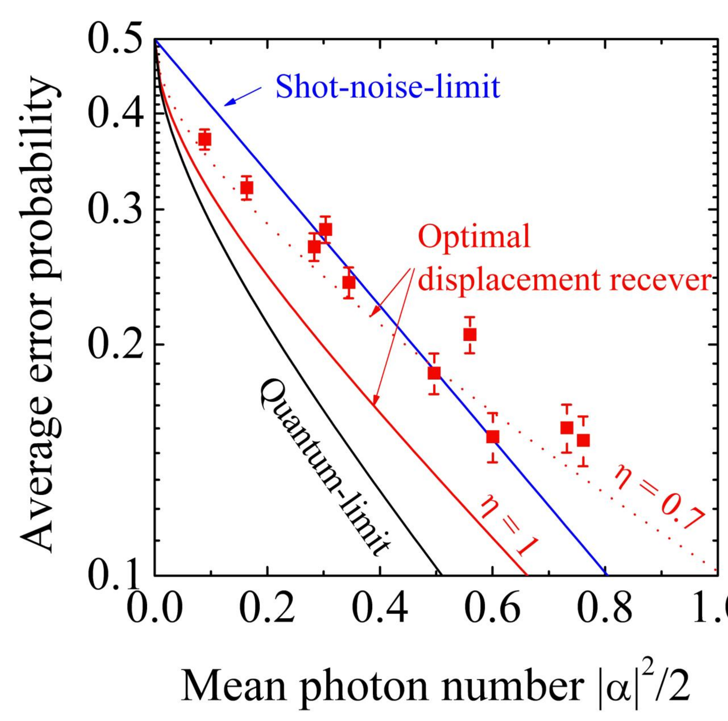
Demonstration of Quantum Receiver

For optical coherent communication systems, the signal discrimination with minimal error is important for long-haul communication. The signal discrimination limit is well known as the shot-noise limit (SNL) for on-off keyed signals. The SNL is achieved by using a photon detector. However, the SNL is not the fundamental quantum limit of optical communications. In the quantum detection theory, it has been predicted for a long time that the fundamental quantum limit of an average error rate is smaller than that of the SNL.

We demonstrate a quantum receiver showing error rates outperforming the SNL of the on-off keyed optical coherent signals.



Concept of quantum receiver. Signals are displaced optimally and then detected using a photon detector, which discriminates between the "on" and "off" states.



Experimental results of signal discrimination performance of our quantum receiver.

Collaborated with NICT AIST Institute of Quantum Science NIHON UNIVERSITY