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Improved single-photon detector performance

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Abstract: High efficiency single-photon detectors are needed for many applications including quantum cryptography and linear-optics quantum computing. We present experimental results showing improved detection efficiency of silicon avalanche photodiodes by reducing reflective losses.

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Quantum logic operations can be performed on single-photon qubits with linear optical elements, additional ancilla photons, and post-selection based on the results of measurements on the ancilla photons [1]. It is now well-known that linear-optics quantum computing requires detectors capable of responding to a single photon with efficiency as close to unity as possible. Such high-efficiency detectors are also needed for quantum cryptography and loophole-free tests of Bell inequalities, and may find other technological applications.

Kwiat *et al.* reported a detection efficiency of 76% for silicon avalanche photodiodes (Si APD's) [2, 3]. These authors noted that substantial reflective losses were present, both from the detector window and from the detector itself.

We present experimental results showing further improvements in detection efficiency by reducing the reflective losses. The specular reflection from detector and its windows is sent to a second detector. The diffuse reflectance from the detector is refocused by a hemispherical mirror. This mirror has a central hole so the incident light (and the specular reflection) can pass through. The second detector could be replaced by a retro-reflector, but its presence allows the specular reflective losses to be directly measured.

Specular reflections from the detector of nearly 16% were reported by Takeuchi *et al.* [4] for the cryogenic visible light photon counter (VLPC), and they used a refocusing mirror to reduce this loss to 2.4%. To our knowledge, the use of refocusing optics has not been reported with Si APD's. See Figure 1.

Figure 1. The light reflecting off the detector windows is sent to a second detector. Hemispherical refocusing mirrors collect diffuse reflected light off the detector.

It is also desirable to have a photon number resolving detector. That is, a detector capable of distinguishing one incident photon from two, or more generally, N from $N+1$. Some cryogenic detectors have the capability to do this [4,5], and there are atomic physics proposals as well, such as [6,7]. An array of beamsplitters and single-photon detectors also has some multiphoton analyzing power, though it has poor scaling. It is also possible to time-multiplex the input of a single detector using fiber-optic 50/50 beamsplitters and fiber delay lines. Using m beamsplitters results in 2^m possible time-bins, see Figure 2. The advantage of this scheme is that it requires no active switching elements, however reducing losses in the fiber-optic components is critical.

Figure 2. Time-multiplexing a single detector using fiber-optic 50/50 beamsplitters gives multiphoton resolution.

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