On Single and Entangled Photon Sources

Quantum and nano optics are ever growing areas of research that study the behavior of light on the quantum and nano scales. A leading topic in this area is quantum entanglement which considers the connection between the states of two photons that may or may not be separated over a large physical distance. In order to research this and other leading topics, experimenters require the ability to manipulate single photons at a time. In this essay, I will discuss the necessity and design of single photon sources and entangled photon sources. Since I have had more experience with the former than with the latter, I will speak mostly on single photon sources and then I will briefly discuss the concepts of entangled photon sources.

- Single photon sources

Light that we experience in daily life is very different from the light required for single photon experiments. Our world is illuminated by light from thermal sources such as light bulbs or the sun. These photons are created by thermal processes in which excited atoms return to their ground state by releasing a photon of a certain wavelength. Since this process happens in many atoms which are closely packed together, there is no method of precisely controlling the flow or energy of the photons. The process of releasing photons is completely random so that the distribution of photons is evenly, randomly distributed. This is good for our daily life because it allows us to see but it is not good when we want to study single, individual photons. We cannot discriminate and remove a single photon of a particular specification from the randomly distributed thermal photon source.

In the middle of the 20th century, the development of coherent light sources advanced the study of optics much closer to the level of single photons. Through the uniform stimulation action of a laser, lasers produce photons of the same wavelength which all share a definite phase relationship. To the researchers at the time, this meant that the photons produced were much more uniform in time and space. This made studying light much more manageable and controllable. Coherent beams of photons could be separated and combined so that researchers could study their interactions with each other. Through this, researchers were able to observe and study the interference of coherent light.

Recently, however, we have been exploring the areas of quantum optics and nano optics. This requires us to look into the interactions of photons on the single photon level. For example, to study the wave-particle duality of photons, it would be useful to observe a single photon behaving as a particle and a wave at the same time. This was previously impossible to do with ordinary, thermal light but now with a coherent beam of photons, experimentalists believed they could attenuate a beam to the point where they could separate photons in time and space such that it would be possible to study them individually.

This turns out to be a very good approximation for a single photon source but it does not work perfectly. By strongly attenuating a photon beam, it is possible to separate emitted photons in space and time. Through mathematics, we can estimate the number of photons per meter that we would expect from an attenuated beam. However, the statistics behind this breaks down when we get close to the single photon level. This is a result of quantum physics. Photons are bosons which, put simply, means they like to be together. The travel in groups and “bunch” together. On the single photon level, simple statistics fails to take this into account. The simple method of statistics assumes that the beam of photons is evenly distributed like a thermal source but this is not the case.

In order to produce a beam of photons that is completely separated in space and time (anti-bunched), a special single photon source is needed. Single photons cannot reliably be created from an attenuated laser beam so new sources must be introduced that will create at most one photon at a time. Producing single, anti-bunched
photon is extremely difficult and is a current area of research today. A current method of creating single photons is to focus a laser onto a single fluorescing molecule. Doing so excites the molecule until it releases a photon and returns to its ground state. Due to fluorescence lifetime, the molecule will only release a single photon at a time and so it acts as a single photon source.

Doing this is very difficult. It requires a sample of single emitters to be prepared such that they are evenly spaced apart in the sample. A laser must then be focused onto a single one of the emitters so that it will excite only one molecule at a time. But unfortunately, we do not completely understand the nature of the quantum-dot fluorescent material and they sometimes die or exhibit a behavior called “blinking” where they do not emit photons for a period of time. More research must go into the development of an efficient means of creating single photons.

Once we can reliable control and produce single photons, we will be able to use them in quantum communication and cryptography. Sending data between two points using single photons as a signal will be extremely secure since the receiver will notice if an eavesdropper has intercepted photons from the data stream.

- **Entangled photon sources**

Entanglement is a quantum mechanical behavior of a pair of photons to have their states tied together no matter how far apart they are in space. In other words, if measurements are performed on one photon’s state at one point in space, those measurements will directly affect the state of its entangled photon which could be at any other point in space. Even more interesting, the pair of photons appear to “communicate” information about their states to each other instantaneously. This would suggest that they are transmitting information to each other at speeds greater than the speed of light. Quantum entanglement is a relatively new and growing area of research that asks the question of how two particles separated over vast distances could instantly know about each others states.

To study this, researchers need a method of creating single pairs of entangled photons. The most popular method of doing so today is through a spontaneous parametric down-conversion process. This process involves sending a photon through a nonlinear crystal which splits the photon into a photon pair which observe the laws of the conservation of energy and momentum. Further, their polarizations are correlated to each other such that they are either parallel or perpendicular to each other. This is an inefficient process as only 1 out of \( \sim 10^{10} \) photons is split into a pair inside the crystal.

Using entangled photon sources, experimenters can test the entanglement hypothesis by changing the state of one photon and observing the other. This is a popular area of research today as it may be applicable to quantum communication and cryptography. With a pair of entangled photons, it will be easy to detect if a photon has been intercepted by an eavesdropper since its entangled photon will exhibit a change of state as well. But as with single photon sources, it remains a topic of research to develop better methods of creating and manipulating efficient single and entangled photon sources.

- **Conclusions**

Single photon and entangled photon sources are an exciting topic in research today. When explored and developed, they will be extremely useful tools in secure communication around the world. Furthermore, the opportunities do not end with communication: learning about entanglement and single photons will give a great deal of insight into the nano and quantum mechanical properties of our universe. But first, we must continue to develop the technology and methods of creating single and entangled photons.

**Sources:**
“Single photon sources for secure quantum communication”, Svetlana Lukishova, Institute of Optics, University of Rochester


