Application of optical near field technology in broadcast interconnects

Conventional broadcast interconnects are marred by diffraction limit of light, thereby leading to bulky systems. As multiple functional blocks that consisitute the broadcast interconnects require the same input data, the system efficiency gets degraded. The advent of dressed photon technology has ushered in novel nanophotonic devices whose nanomertic structures can go beyond the diffraction limit. But at the same time, the above mentioned nanophotonic devices have to cope up with stringent interconnection requirements in order to get coupled to external signals, which are discussed in the present lecture.

1 Nanophotonic implementation of broadcast type interconnections

In memory-based architectures, different functional blocks that constitute the interconnects, require the same input data. Nanophotonics is best suited for such broadcast operations and can be related to imaging optics and can couple to the far field. But to ensure unidirectional transfer of exciton energy between neighbouring quantum dots, optical near field interactions and the subsequent intra sub level relaxations should occur. As this involves both far field coupling and near field coupling to occur simultaneously, stringent interconnection requirements have to be met. These stringent requirements can be satisfied by proper manipulation of the sizes of the quantum dots, so that at a particular set of quantum dots can act as an optical switch, thereby allowing unidirectional exciton energy transfer. At the same time, the above mentioned set of quantum dots should not interfere with other channels even if the entire system is illuminated in the same area. Thus even though stringent broadcast interconnection requirements are imposed, they can be satisfied by appropriate manipulation of the quantum dot sizes. A nanophotonic switch comprising of three CuCl quantum dots of appropriate sizes is portrayed as an animation in Figure 1. Based on this concept, a content addressable memory whose output is a broadcast system comprising of three nanophotonic switches is depicted in Figure 2.

2 Theoretical perspective

Ohtsu research group considered a nanometric system comprising of nanophotonic switches arranged in arrays of different nanophotonic circuit blocks. The size of the area in which the nanometric system is distributed is comparable to the wavelength of light. When the multiple input quantum dots are illuminated by the conventional propagating light, all the multiple quantum dots accept the same input data from the diffraction limited far field instantaneously. This is made possible by tuning the optical frequencies of the multiple quantum dots. By this arrangement, light gets coupled to the electric dipole allowed energy levels of the multiple quantum dots. Thus the nanometric system comprising of arrays of semiconductor quantum dots undergoes frequency multiplexing. The nanophotonic switches are mainly CuCl semiconductor quantum dots having appropriate sizes. Usually, the multiple quantum dots are chosen as those forming a quantum dot trio in the ratio $1:2:\sqrt{2}$. This can be elaborated as follows. Let the set of linearly independent frequencies that comprise the input broadening channels be $\Omega_i = \{\omega_{i1}, \omega_{i2}, \omega_{i3} \ldots \omega_{im}\}$, where m denotes the number of input frequencies. In a similar manner, let the set of linearly independent frequencies

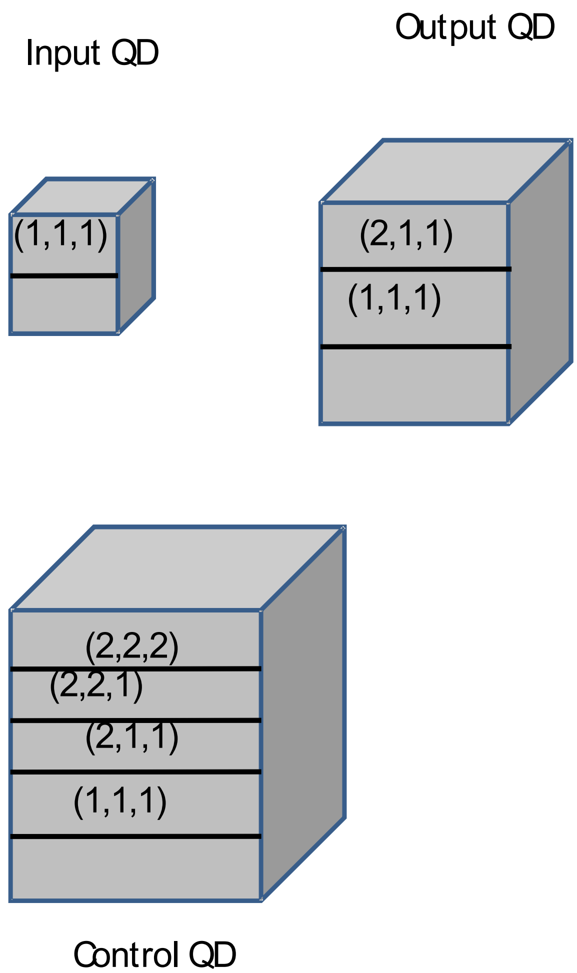

Fig. 1: Nanophotonic switch.

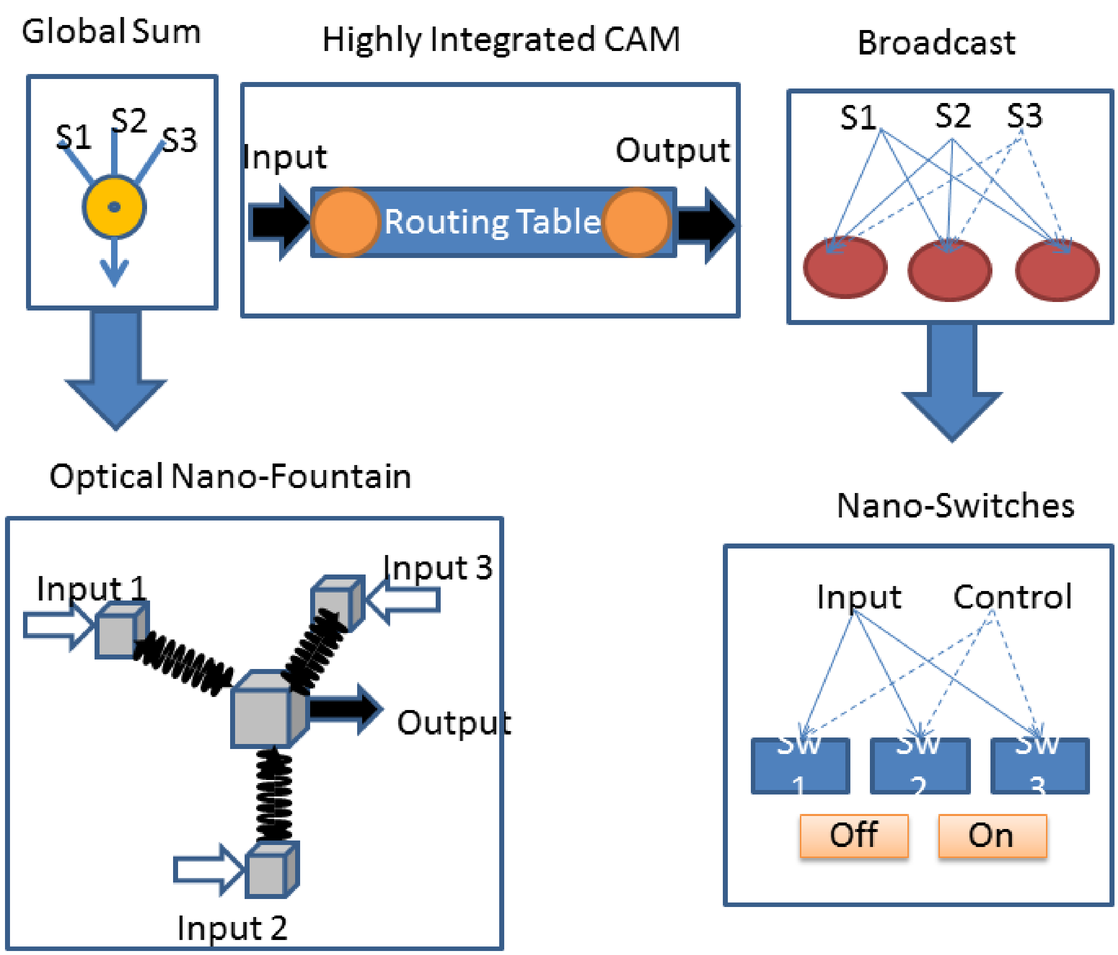

Fig. 2: A content addressable memory system.

that comprise the output channels be $\Omega_0 = \{\omega_{01}, \omega_{02}, \ldots \omega_{0n}\}$, where n denotes the number of output frequencies. Also, let the set of linearly independent frequencies that are needed for internal devices operations be $\Omega_j = \{\omega_{j1}, \omega_{j2}, \ldots \omega_{jk}\}$ where k denotes the number of internal devices frequencies. Thus for global data broadcasting, linearly independent sets of input, output and internal frequencies ω_i, ω_0 and ω_n are assigned respectively.

Potential barrier of the CuCl quantum dots in the NaCl matrix can be considered to be infinitely large. The quantized Z_3 exciton energy levels (n_x, n_y, n_z) can be calculated from the relation

$$E_{(n_x,n_y,n_z)} = E_b + \frac{(n_x^2 + n_y^2 + n_z^2)\pi^2\hbar^2}{2\mu(L - a_B)^2}, \tag{2.1}$$

where E_b is the energy of the bulk Z_3 exciton, μ the center of motion of mass of the exciton, n_x, n_y and n_z being the quantum numbers of the center of mass motion and $a = L - a_B$ is the effective side length. From Eq. (2.1), it can be noted that the even quantum numbers exciton energy levels are electric-dipole forbidden energy levels. As discussed in section..., to form a nanophotonic switch comprising of three quantum dots, their sizes should be in the ratio of $1:2:\sqrt{2}$ in order to ensure unidirectional exciton energy transfer. As the energy levels $(1,1,1)$ for each input quantum dot can also get coupled to the far field excitation, they initiate data broadcasting. An important point to note is that the energy sub levels for the the inputand output channels should not overlap with each other. If this happens, unidirectional exciton energy flow does not occur. Moreover, if any quantum dots are used internally for enhancing the optical near field coupling, the dipole allowed energy sub levels for those internally used quantum dots should not be used for the input channels, as the inputs are the perrogative of the far fields. Thus if resonant levels exists for those cases, internal near field interactions will not tape place properly, once again failing to guarantee unidirectional exciton energy flow. This calls for a stringent frequency partitioning among the input, internal and output channels. Thus for global data broadcasting, one should assign input, internal and output frequencies in an exclusive manner.

3 Experimental observation

Ohtsu research group considered a nanomertic system consisting of CuCl quantum dots that were distributed in a inhomogeneous manner in a NaCl matrix at a temperature of $22K$ as portrayed in Figure 1. In order to have a unidirectional exciton energy transfer, a nanophtonic switch comprising of atleast three quantum dots were considered and atmost tow input light beams, say IN 1 and IN 2 were illuminated. When both input signal were present, the output signal was obtained within a small area. Ohtsu research group observed that when the IN 1 and IN 2 were illuminated with input signals having operating wavelengths at $325nm$ and $384.7nm$, respectively, the output signal was measured by scanning an area of approximately $1\mu m \times 1\mu m$ by a near field fiber probe. An important point to be noted was that the sizes of the quantum dots forming the nanophotonic switch were to be maintained in the ratio $1:2:\sqrt{2}$. Thus they were able to make a quantum dot trio that existed in the ratio $1:2:\sqrt{2}$ to operate as an optical switch and at the same time were able to prevent them from interfering with other channels even thought the input signal illuminated the same array of quantum dots.

4 Additional reading and references

1. M. Ohtsu, K. Kobayashi, T. Kawazoe and T. Yatsui, Principles of Nanophotonics (CRC Press, New York, 2008).

2. M. Ohtsu (Ed.), Progress in Nanophotonics 1 (Springer-Verlag, Berlin, 2011).

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