Lasers pumped Quantum Dynamics in Nanostructured arrays for Computing

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ABSTRACT

Quantum computation uses qubit in superposition and entanglement states providing more sophisticated computation ability regarding today's computers. For that purpose of developing a novel computer concept exploiting quantum dynamics at the nanoscale, we joined an EC H2020 program consortium named COPAC [1]. We propose to analyze the nonlinear 2 dimensional optical response of assembled nanostructures in solid arrays to a sequence of short laser pulses. Based on 2D maps of the stimulated emission we implement a novel paradigm for parallel information processing. Within the COPAC project, we, in KiloLambda, will develop the device nanostructure and engineering design.

Keywords: Quantum computer, nanostructure, nanophotonics, parallel information processing

1. INTRODUCTION

Quantum computing makes direct use of quantum-mechanical phenomena, such as superposition and entanglement, to perform operations on data. Quantum computation uses quantum bits, qubit, which can be in superposition of states as opposed to common digital computing that required the data be encoded into binary digits (bits), each of which is always in one of two definite states (0 or 1). Using these two principles (superposition and entanglement), qubits can act as more sophisticated switches, enabling quantum computers to function in ways that allow them to solve difficult problems that are intractable using today's computers. Some of the long term applications for quantum computers can be simulation of physical processes such as photosynthesis, opening new frontiers in green energy, or pushing artificial intelligence to a vastly higher level of sophistication. In order to realize this vision, we need first to figure out how to actually build a working concept of a quantum computer that can perform more than the simplest operations.

We joined an EC H2020 consortium named Coherent Optical PArallel Computing (COPAC) [1] for developing a novel concept of a computer exploiting quantum confinement and non linear optics. We plan to use the dynamic response of assembled nanostructures in solid arrays to short laser pulses and implement a novel paradigm for parallel information processing. The discrete quantal level structure of nanosystems provides a memory at room temperature. Inputs are delivered simultaneously to all the levels by broadband laser pulses and the dynamical response implements the logic in parallel.

1.1 Coherent Optical PArallel Computing (COPAC)

COPAC is a transformative novel area in computing both because of the technology, coherent photonics and because of the specialized parallel processing of large amounts of information. In the COPAC consortium, we will make foundational experimental, theoretical and algorithmic innovations to demonstrate a new technological paradigm for ultrafast parallel multi-valued information processing. We aim to develop a ground-breaking nonlinear coherent spectroscopy combining optical addressing by short laser pulse sequences and spatially macroscopically resolved optical readout to achieve unprecedented levels of speed, density and complexity. Two key high-risk / high-reward pioneering elements are the quantum engineered coherent concatenation of units and the multidirectional optical detection. Background papers on theoretical models and simulations by Fresch et al and Yan et al are presented in ref no.2 and no.3. Experimental demonstrations on molecules [4,5] and tailored nanosystems [6,7] in self-assembled arrays of increasing complexity [8,9,10], integration into a device and novel hardware and matched compilers [11,12] will be delivered. Preliminary experimental demonstrations of the response of solutions and of engineered nanoarray films are available as is the validation of logic operation in parallel.

The consortium use the dynamic response of assembled nanostructures in solid arrays to implement novel paradigms for parallel information processing. The discrete quantal level structure of nanosystems provides a memory at room temperature. Inputs are delivered simultaneously to all the levels by broadband laser pulses and the dynamical response implements the logic in parallel. For the short time scale probed, disorder and environmental fluctuations are not detrimental factors but are actually essential for the simultaneous multidirectional optical readout at the macroscopic level.

The long term vision of COPAC is the application of atomic and molecular state resolved controlled quantum dynamic processes towards information processing. Within this our targeted breakthrough is a novel prototype device for parallel logic engineered to industry standards and with suitable compilers.

We, in KiloLambda [13,14,15], will develop the device engineering design for the overall quantum computer. Within current paper we will discuss the device configurations as designed for the COPAC project.

2. PROPOSED PROTOTYPE SYSTEM

The design for the implementation of the directional decomposition of a multivariable logic function in parallel is described in ref 3, and is presented in the scheme of a prototype system is illustrated in Figure 1.

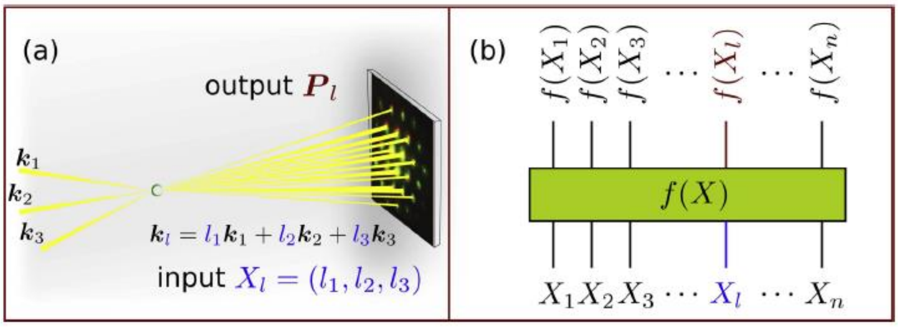

FIG. 2. Schematic representation of the implementation of the directional decomposition of a multivalued function, $f(X_1, X_2, \ldots, X_n)$, by the decomposition of the full macroscopic polarization response of the ensemble of molecules in the phase matching directions. (a) Schematic view of the phase matching conditions in which directional polarization components, P_l, that can be detected when an ensemble of molecules interacts with three laser pulses of wave vectors $\mathbf{k}_1$, $\mathbf{k}_2$, and $\mathbf{k}_3$. The set of integers (l_1, l_2, l_3) that defines the phase matching direction, $\mathbf{k}_l = l_1\mathbf{k}_1 + l_2\mathbf{k}_2 + l_3\mathbf{k}_3$, corresponds to the values of three variable logic input X_l. (b) The values of the outputs $f(X_l)$ of the function $f(X)$ for the inputs X_l's are computed in parallel in the phase matching directions and their values given by the binned values of the partial polarizations, P_l, emitted in each of the directions $\mathbf{k}_l$.

Figure 1: schematic presentation of implementation of the directional decomposition of multivalued function (Fig. 2 @ ref 3, taken with permission)

Based on the schematic illustration presented in Figure 1, we propose a prototype system illustrated in Figure 2. Looking now into the system components, we can identify the following:

a) Laser source, having controlled power and timing, is creating pulses k1, k2, k3 and directing them into a single point, where they interact with the particles in the nanostructure. Laser sources of ps duration in the visible range are available commercially today, so are the needed lenses and timing equipment. Thus, for early design of prototype we can think of using available off-the shelf equipment. However, those lasers are still too bulky to be considered for the goal product. Laser power, wavelength, pulse duration and size are parameters that will be taken into account in the design of a prototype system.

b) Nanostructure device, where the selected nanoparticles will be embedded in a solid transparent matrix, is one of the main development challenge of this project. This kind of nanostructure device does not exist commercially and is not available anywhere. We will refer to this device definition and parameters within the following sections.

c) Detector array system, where the phase matched beams are measured. Detection can be performed via a camera or assembly of commercial detectors and components.

d) Computerized input-output system including dedicated software will be developed within the scope of the COPAC project

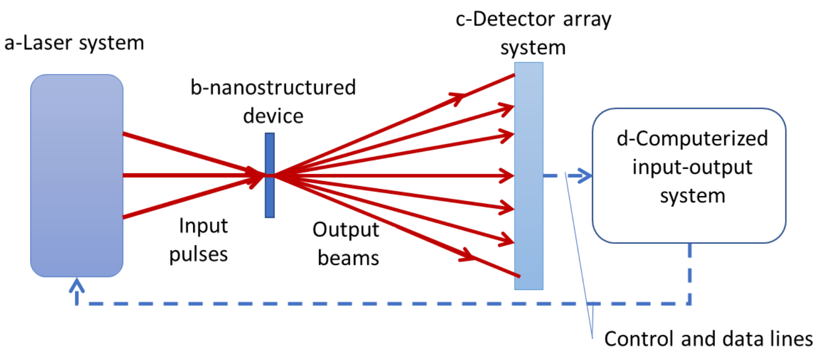

Figure 2: proposed prototype system for the COPAC project

The major challenges of the COPAC project:

- Nanostructure device development and testing
- Software for computerized input-output system, development and testing

Within this paper, we will focus mostly on the first part of the design of the nanostructure device.

3. DEVICE PARAMETERS

Our first task is modeling and design of the nanostructure device. In order to perform this task, we studied previous work [8,7] and project communications regarding the nanostructures samples used for previous experiments. Based on this study we define a series of adequate parameters for describing a prototype device (refer to Figure 3).

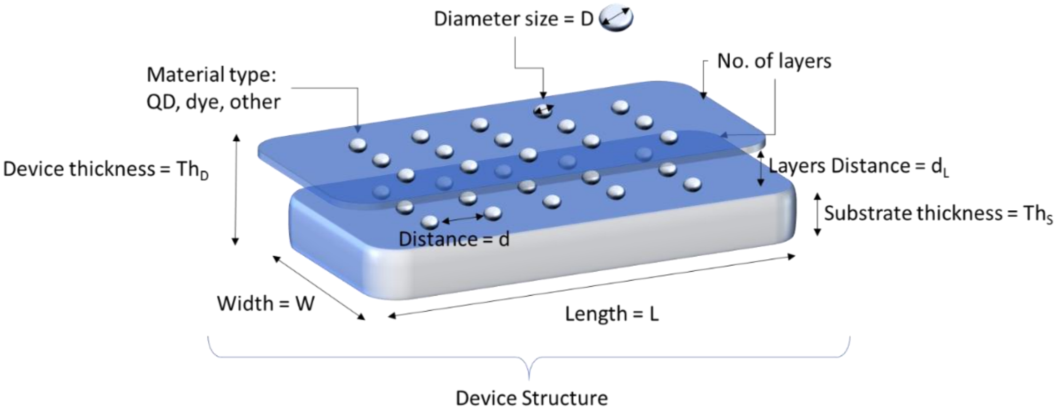

Figure 3: Device parameters

The device is composed of a transparent substrate, with an array of nano-particles and/or quantum dots (QDs) embedded within a polymer matrix. We define various parameters to be used as a basis set in the modeling and simulation of this prototype device. First, we need to define the particles nature: type, size and arrangement. Particle major type can by either molecules or QDs families, which should be defined more specifically for the exact materials. Particles should be placed with no order within the device and no interaction in between them. Molecules in solution are a good example for such a dis-ordered device. However, if we refer to QDs in solid state arrangement, we can assume that even though there are large amount of them, only the very few close together interact in between them. So, there is still a fulfilment of the requirement of no interaction between the QDs.

For lifetime issue we should take into account the following mechanism:

- Temperature: storage and operation temperatures of the device influence the device degradation mechanism
- Laser: absorption of around 10% of the laser beam within the device implies a degradation over time, or even a permanent damage within the laser impinging area. A careful choice of materials and packaging can minimize degradation.
- Oxygen: sample should be covered with oxygen barrier in order to reduce degradation be oxygen. Oxygen barrier can be dielectric layer deposit by evaporation, or wet coating.

4. SUMMARY

We joined an EC H2020 consortium named Coherent Optical PArallel Computing (COPAC) [1] for developing a novel concept of a computer exploiting quantum confinement and non linear optics. COPAC plan to use the dynamic response of assembled nanostructures in solid arrays to short laser pulses and implement a novel paradigm for parallel information processing. The discrete quantal level structure of nanosystems provides a memory at room temperature. Inputs are delivered simultaneously to all the levels by broadband laser pulses and the dynamical response implements the logic in parallel. Our role in this project is to develop the device engineering design for the overall quantum computer.

5. REFERENCES

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