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Ultrafast All-Optical Computing with CoTCPP Surface-supported Metal–Organic Framework Nanofilms

Anam Saifi* and Sukhdev Roy

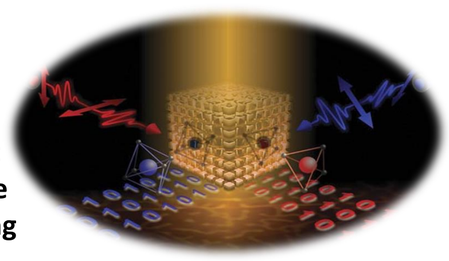
Department of Physics and Computer Science, Dayalbagh Educational Institute, Agra, India

anamsaifi@dei.ac.in

INTRODUCTION

All-optical Computing

Advantages
- Efficient
- No Crosstalk
- Ultrafast Speed
- Ultracompact & Low Cost
- Scalable & Reconfigurable
- Less Energy & Low Heating

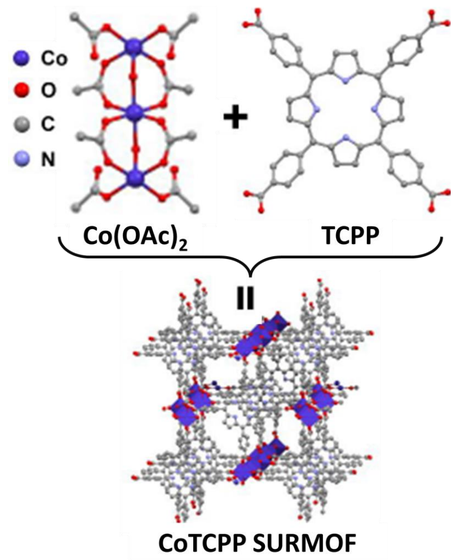


Challenges
- Cascadibility
- Complete Logic Functionality
- Logic Level Restoration
- Good I/O Isolation
- Better Fan Out
- High Photothermal Threshold

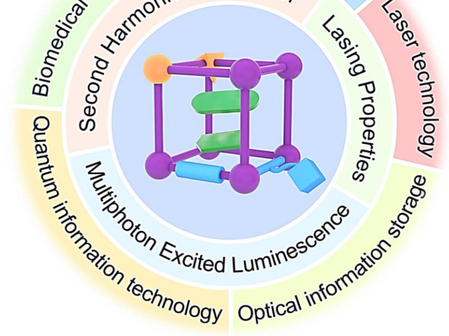
Desirable : Ultrafast Switching Time, Low Switching Power & High Switching Contrast

Surface-supported Metal-Organic Frameworks (SURMOFs)

Salient features
- Ultra strong & tailored nonlinear optical properties
- High porosity, crystallinity and structural tunability
- High photothermal and photochemical stability
- High surface area and surface interaction
- Biocompatible and biodegradable
- Easy functionalization and post-synthetic modifications



Applications



- Crystalline and highly oriented porphyrin-based SURMOFs are covalently assembled on quartz substrates.
- Cobalt ions and porphyrin molecules ([5,10,15,20-(4-carboxyphenyl) porphyrin], TCPP), in which Co-oxo trinuclear clusters, as the secondary building units, are connected with ditopic TCPP linkers, yielding a closely packed 3D structure.

Li, C., Qian, G., & Cui, Y. Inf. & Funct. Mater. (2024).

OBJECTIVES

(i) To theoretically study the ultrafast transition from saturable absorption (SA) to reverse SA (RSA) in CoTCPP SURMOF nanofilms.

(ii) To study the effect of input intensity, concentration, film thickness and nonlinear absorption (NLA) coefficients on transmittance.

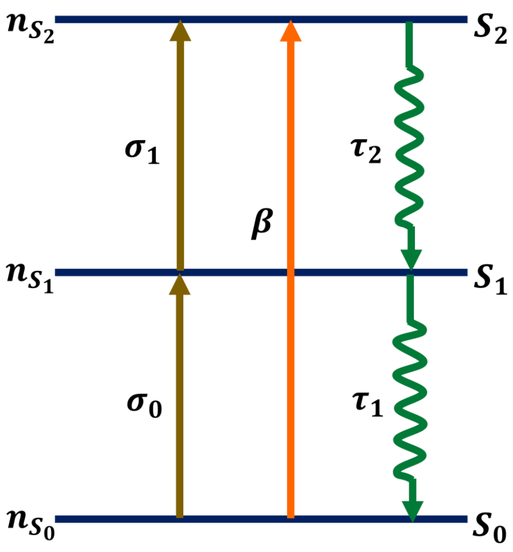
(iii) To optimize these parameters to design low-power and high contrast ultrafast all-optical NOT, OR, AND, XOR, universal NOR & NAND logic gates.

(iv) To design a novel encryption–decryption scheme based on nonlinear absorption using ultrafast all-optical XOR logic gate.

(v) To design an all-optical diode with CoTCPP SURMOF nanofilms and ZL-61.

THEORETICAL MODEL

Three-level energy diagram



Rate Equations

$$\frac{dn_{S_0}}{dt} = -\frac{\sigma_0 I_{in} n_{S_0}}{h\upsilon} - \frac{\beta I_{in}^2}{2h\upsilon} + \frac{n_{S_1}}{\tau_1}$$

$$\frac{dn_{S_1}}{dt} = -\frac{\sigma_1 I_{in} n_{S_1}}{h\upsilon} + \frac{\sigma_0 I_{in} n_{S_0}}{h\upsilon} - \frac{n_{S_1}}{\tau_1} + \frac{n_{S_2}}{\tau_2}$$

$$\frac{dn_{S_2}}{dt} = \frac{\sigma_1 I_{in} n_{S_1}}{h\upsilon} + \frac{\beta I_{in}^2}{2h\upsilon} - \frac{n_{S_2}}{\tau_2}$$

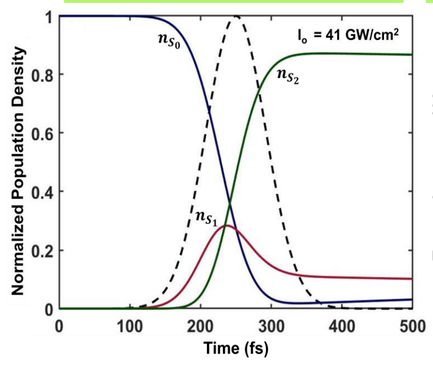
with $n_{S_0} + n_{S_1} + n_{S_2} = n$

Transmitted Intensity :

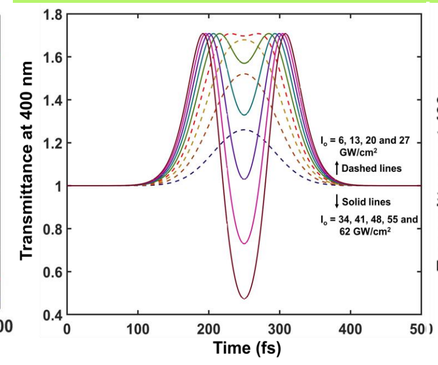
$$\frac{dI}{dz} = -(\alpha_0 + \beta I + \gamma I^2) I$$

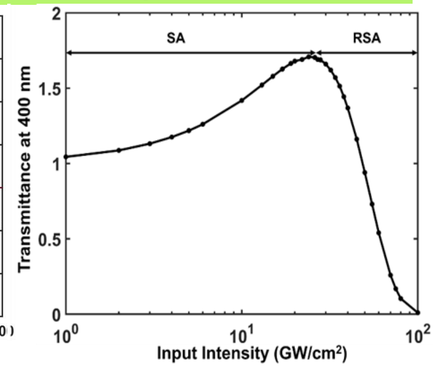
RESULTS

Population Dynamics



Effect of Variation of Input Pulse Intensity on Transmittance



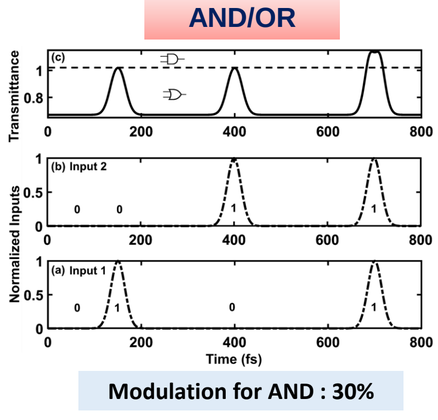


λ = 400 nm, L = 400 nm, τ_p =100 fs

For both SA and RSA, Percentage modulation increases with increasing intensity.

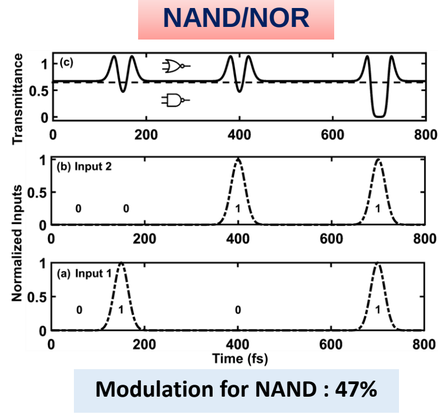
Design of Ultrafast All-Optical Parallel Logic Gates

AND/OR



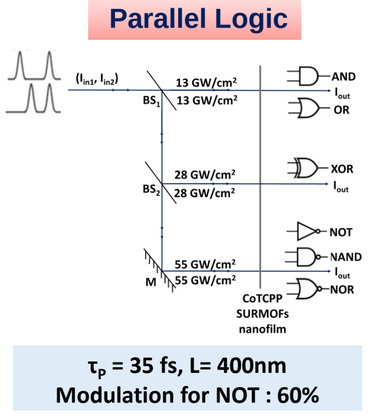
Modulation for AND : 30%

NAND/NOR



Modulation for NAND : 47%

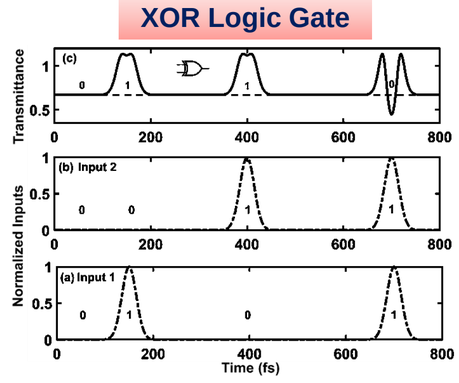
Parallel Logic

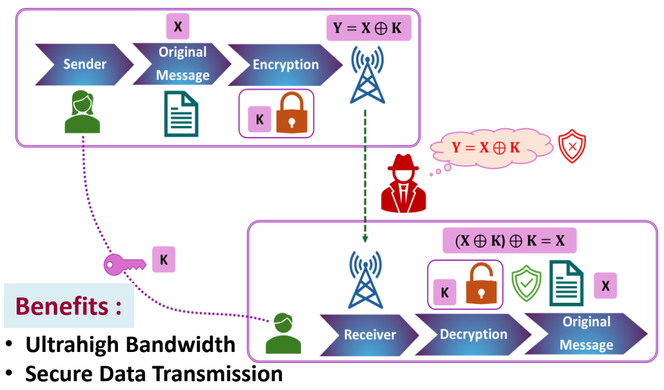


τ_p = 35 fs, L= 400nm
Modulation for NOT : 60%

Encryption-Decryption using All-Optical XOR Logic Gate

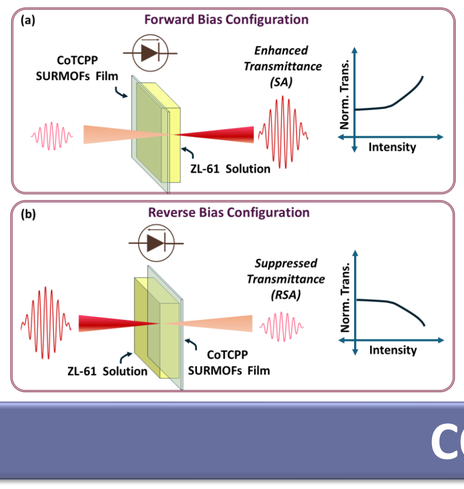
XOR Logic Gate

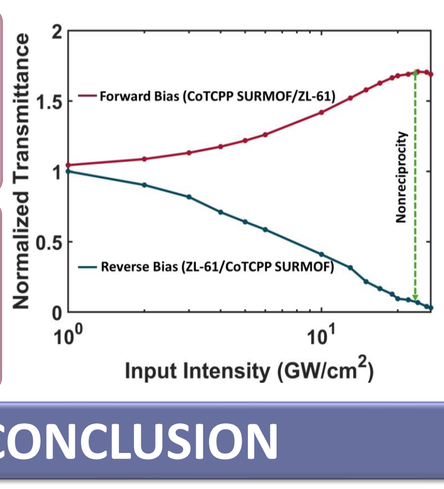




Benefits :
- Ultrahigh Bandwidth
- Secure Data Transmission

Design of Ultrafast All-Optical Diode with CoTCPP/ZL-61





Comparison Table	
Material	Non-reciprocity (dB)
Sb/C_{60}	5
FLG/C_{60}	6.2
BLG/C_{60}	4.9
CoTCPP/ ZL-61	17

CONCLUSION

- Detailed theoretical study of ultrafast nonlinear absorption has been carried out.
- Designed high contrast, low power, ultrafast all-optical AND, OR, NOT, universal NAND, NOR and XOR logic gates.
- Demonstrated all-optical encryption-decryption using all-optical XOR logic gate.
- All-optical diode with CoTCPP SURMOF/ZL-61 results in 17 dB nonreciprocity.
- High bit rate : 9 Tbits/s at I_o = 55 GW/cm² with optimum pulse interval 110 fs.
- Present analysis highlights the advantages and applicability of the CoTCPP SURMOF nanofilms for ultrafast information processing and ultrahigh bandwidth.

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