# Electrically-Driven Light Emitter in Tailor-Made Photonic Crystal Cavity

**Anna P. Ovvyan[1,5,+], Felix Pyatkov[2,3,+], Min-Ken Li[4], Helge Gehring[1], Fabian Beutel[1], Sandeep Kumar[2,3], Ralph Krupke[2,3,4,*], Wolfram H. P. Pernice[1,*]**

*[1]Institute of Physics, University of Münster, Heisenbergstraße 11, 48149 Münster, Germany*
*[2]Institute of Nanotechnology, Karlsruhe Institute of Technology, Hermann-von-Helmholtz-Platz 1, 76344 Karlsruhe, Germany*
*[3]Department of Materials Science, Technische Universität Darmstadt, Otto-Berndt-Straße 3, 64287 Darmstadt, Germany*
*[4]Institute for Quantum Materials and Technologies, Karlsruhe Institute of Technology, Hermann-von-Helmholtz-Platz 1, 76344 Karlsruhe, Germany*
*+ contributed equally to this work.*
[5]ovvyan@uni_muenster.de, [*]ralph.krupke@kit.edu, [*]wolfram.pernice@uni_muenster.de

**Abstract:** We for the first-time developed telecom hybrid graphene photonic crystal cavity device with an integrated carbon nanotube ensuring high enhancement of its electroluminescent signal and demonstrating the supervision of its intensity. 

## 1. Introduction

One of the strongest demands and outstanding challenges of advanced quantum applications is an efficient and scalable integration of light sources in photonic circuits and supervision of its emitting properties leading to high quantum yield [1]. The Single-walled Semiconductor Carbon Nanotube (sCNT) is one of perspective nanoscale photon sources with stable excitonic emission, which shows quantum behavior at cryogenic and at room temperature [2,3]. Thus, in this work we demonstrate the first to our knowledge scalable realization of a hybrid platform with a fully-controlled electrically-driven telecom sCNT-emitter integrated in the photonic crystal (PHC) cavity on chip.

## 2. Hybrid graphene-sCNT $Si_3N_4$ photonic crystal cavity devices

We integrated single chilarity sCNTs emitting in telecommunication wavelength range into tailor-made PHC cavities exactly fitting the spectral characteristics of sCNTs. The electrically-driven hybrid graphene-sCNT photonic circuit, shown in Fig.1. was realized on silicon nitride-on-insulator wafers via specially developed and optimized multi-step electron beam lithography protocol. To enhance the electroluminescence (EL) single sCNTs were scalable placed atop the center of cavities in maximum of electric field resonance modes via our site-selective deposition method [4].

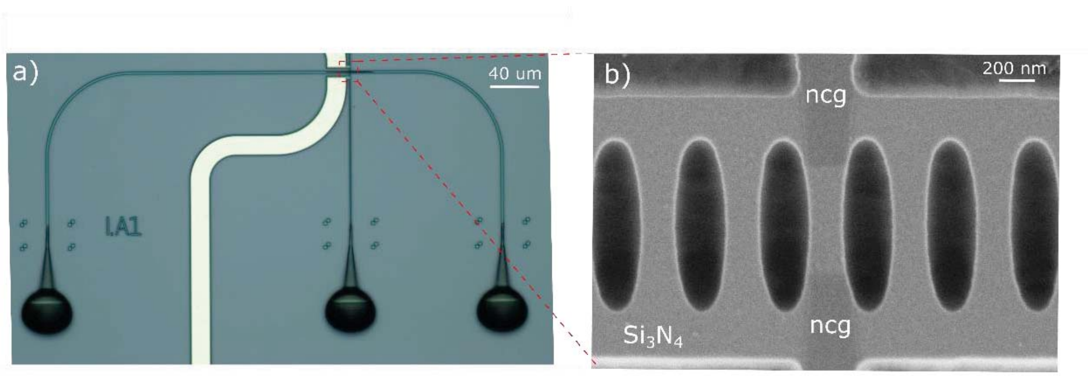


Fig. 1. Hybrid graphene PHC cavity photonic device. a) Micrograph of the device. b) Zoom in into PHC cavity region.

Specially developed and optimized nanocrystalline graphene (ncg) electrodes allow placement of sCNTs directly atop photonic devices and ensure negligible optical insertion loss non-effecting Q-factor of the PHC cavity. In this way we overcome the outstanding challenge of positioning electrodes in the vicinity of photonic circuits where the utilization of standard metal electrodes is limited due to high optical absorption. Furthermore, following the fabrication of nanophotonic circuits, the devices were equipped with 3D couplers [5] realized via direct laser writing, which allow a highly efficient read-out of the enhanced electroluminescence signal.

### 3. Simulated and Experimental results

We electrically excited the sCNT by applying constant current via ncg electrodes on the PHC cavity. Purcell enhancement of spontaneously emitted EL leads to boosting of coupling efficiency ($\beta$ - factor) in the mode in case of spectral, spatial and polarization overlap of electric field pattern of the integrated sCNT and the electric field distribution of the considered resonance mode. This was obtained by tailoring the design and further optimization of the hybrid PHC cavity via 3D Finite Difference Time Domain (FDTD) numerical simulations.

We first to our knowledge demonstrated efficient coupling of electroluminescent sCNT into PHC cavity on-chip and furthermore control of enhanced EL intensity via electrical gating. The EL of the constantly biased sCNT with simultaneously applied back-gate voltage coupled into odd resonance modes of PHC cavity detected via 3D couplers, corresponds to the *turn-on* state is shown by red curve in Fig. 2 b). The experimentally acquired spectrum is in a good agreement with the simulated coupling efficiency spectrum depicted in Fig. 2 a). Variation of the back-gate voltage leads to reproducible modification of excitonic emission and thus suppression of EL signal, which corresponds to *turn-off* state, shown by blue curve in Fig. 2 b). The enhancement factor of spontaneously emitted EL coupled into III-order mode is F=35.

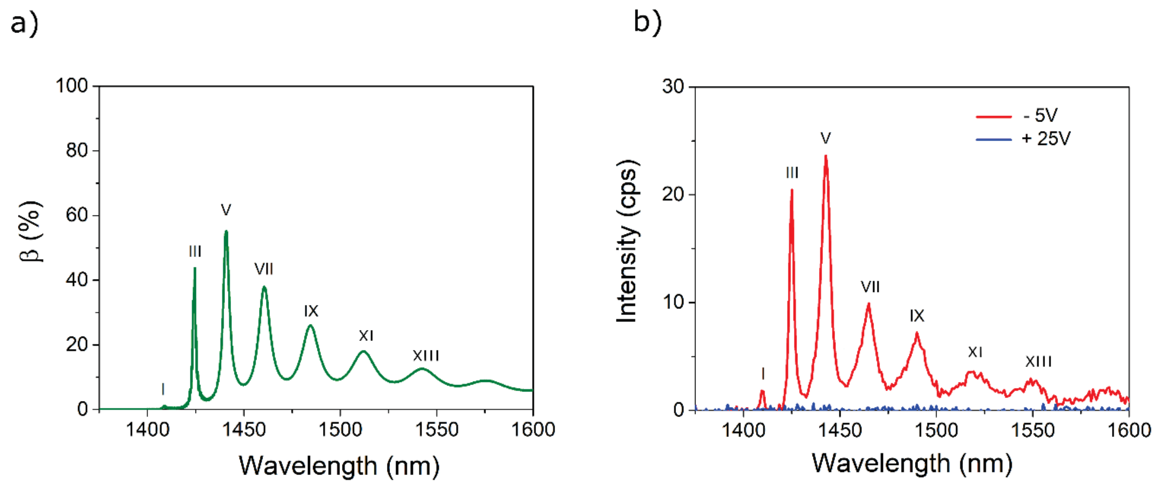


Fig. 2. Simulated and experimental results. a) 3D FDTD simulated coupling efficiency $\beta$ spectrum of sCNT placed atop PHC cavity center. b) Enhanced electroluminescent signal of biased sCNT coupled to the hybrid graphene $Si_3N_4$ PHC cavity, detected at 3D coupler at applied 5V (red curve) and +25V (blue curve) back gate voltage, respectively. The resonance modes are labelled with Roman numbers (I XV).

### 4. Conclusions

For the first time we developed electrically-driven hybrid graphene-sCNT PHC cavity devices, which allow to supervise an enhanced electroluminescent signal in the telecom wavelength range obtaining total *turned on-off* regimes.

### 5. References

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