SEMICONDUCTOR SOCIETY (INDIA)

Semiconductor News

A publication of the Semiconductor Society (India)

https://www.semiconductorsociety.in

January-June, 2024

From the Editors' Desk

Quantum light source is an important initial element for several quantum technology applications. This includes quantum computing, quantum precision extent and quantum protected communication. In the recent past, quantum technology has emerged quickly with the increasing requirement for materials that are capable of introducing quantum emitters.

The single photon emitter is an essential quantum light source which releases a photon at a time and all others photons are considered as identical. Around the world, the researchers have found single photon emitters in many quantum dot materials including InGaAs and GaAs. In addition, single photon emitters are also reported in one dimensional materials such as InP nanowires, carbon nanotube and three dimensional wide bandgap semiconductors GaN and AlN. However, there are many drawbacks reported in single photon emitters. For example low brightness, spectral instability and environmental sensitivity which minimize their applications. The conventional solid-state emitters are usually inserted in three dimensional materials with high refractive index.

One can fabricate quantum emitters with various approaches including physical destruction of material using the tip of a scanning probe microscope, by thermal activation of regular defects, and using an irradiation method with high energetic ions or electrons. The significant progress has been reported in engineering quantum emission in solid state materials. The wide bandgap materials AlN, GaN and hBN are the potential materials for quantum emitters due to their chemical and mechanical stability under severe environmental conditions, wide optical window from ultraviolet to mid- infrared, and nonlinear optical effect.

In the present issue of newsletter, AlN based quantum emitters for quantum computing applications have been discussed.

Uday Dadwal, IIT Delhi
Kapil Narang, SSPL

Contact Details:
Phone No.:- +919999165736
E-mail:- semiconductor.society.in@gmail.com
Website:- https://www.semiconductorsociety.in/

AlN Based Quantum Emitters for Quantum Computing Applications

The rise of AI platforms like ChatGPT has intensified data traffic and integration density in electronic circuits, leading to increased power consumption. In other words, computing systems face challenges in managing the escalating data traffic and integration density, leading to a surge in power consumption worldwide. Unlike its classical counterpart (0, 1 bits only), quantum computing harnesses the power of qubits- quantum bits (0, 1 and multiple states simultaneously of both), thanks to the phenomenon of superposition. This unique property enables quantum computers to tackle complex calculations at speeds unattainable by classical systems. To create qubits in quantum computing, the photonics-based architecture uses quantum emitters (QE) that generate single photons to represent the states of qubits. However, existing quantum emitters suffer from limitations such as low brightness, and environmental sensitivity. We want high-performance emitters capable of integration into solid-state, on-chip devices for practical applications, with a focus on scalable photonic platforms hosting intrinsic or embedded sources of single-photon emission.

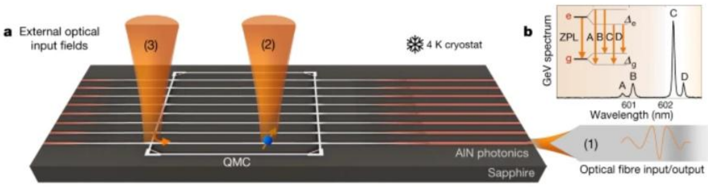

Figure 1: AlN single quantum emitters for quantum computing applications www.nature.com/articles/s41586-020-2441-3 [*Wan, Noel H., et al., Large-scale integration of artificial atoms in hybrid photonic circuits, Nature, 583.7815, 226-231 (2020)*].

Researchers have predominantly explored diamond, hBN, and silicon carbide (SiC) in creating single photon emitters due to their wide bandgap and exceptional optical characteristics. Yet, they have certain limitations when it comes to effectively manipulating and integrating quantum emissions from these semiconductors into scalable systems.

"Recently, defect-based QEs have been reported in an AlN film, a wide bandgap semiconductor with an optical transition energy of ~6.1 eV. Due to the deep confinement energies, these emitters could exhibit photon antibunching at room temperature. Theoretical calculations predicted that atomic defects in AlN could act as candidates for optically addressable spin states. This makes it a promising material platform for quantum information processing. Apart from that, AlN is a commercially important semiconductor compatible with the complementary metal-oxide semiconductor (CMOS) process. Their compatibility with Si substrates and mature fabrication technologies hold promise for the integration of quantum photonic devices into existing semiconductor processes.

Addressing these open challenges will be critical for realizing the full potential of AlN quantum emitters in quantum communication, quantum computation, and quantum sensing.

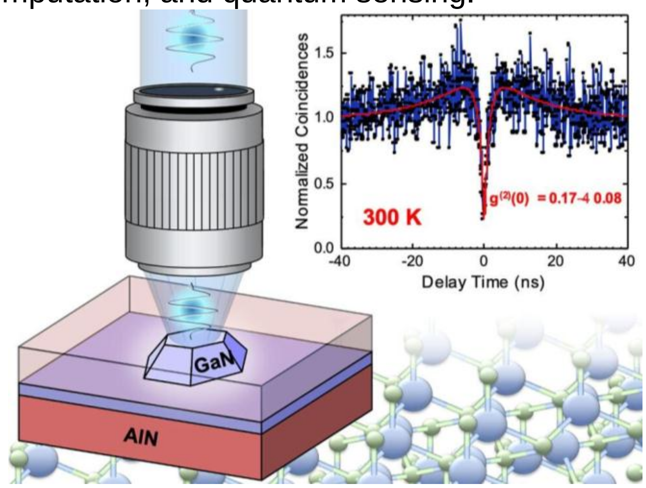

Figure 2: Schematic of the fabricated single photon emitter using ammonia source MBE. It consists of a thick metal polar AlN layer deposited on Si. A few monolayers thick GaN QD was grown and capped by a thick AlN. On the surface, an additional uncapped plane of QDs was grown. The single photon emission was detected by cathodoluminescence. The sample was then patterned using electron beam lithography and subsequent etching [*Johann Stachurski et al., "Single photon emission and recombination dynamics in self-assembled GaN/AlN quantum dots", Light: Science & Applications, 11:114 (2022)*].

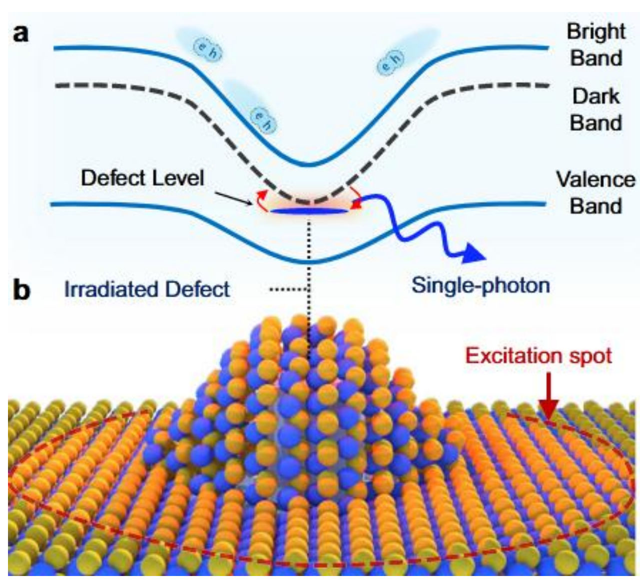

Figure 3: Schematic of a strain and defect engineered WSe_2 single photon emitter. (a) Represents spatial and gap

variations due to strain. The solid blue lines show excitonic bright band and valence band. Dashes gray line represents dark excitonic band. (b) Schematic of a WSe_2 strained over a SiO_2 nanopillars (W atoms in blue and Se in yellow). e–h pairs are neutral excitons created within the excitation laser spot (red dashed line). At the strained region and in the presence of a defect, the dark exciton can become strain tuned to a defect level. This forms intervalley defect excitons. The dark exciton state can recombine through the defect level which gives rise to a bright single photon emission. [*Nathalie P. De Leon et al., "Defect and strain engineering of monolayer WSe_2 enables site-controlled single-photon emission up to 150 K", Nature Communications, 12, 3585 (2021)*].

More information about this article can be found from the following references:

[1] Sutor, R. S., Dancing with Qubits: How quantum computing works and how it can change the world. 2019, Packt Publishing Ltd.

[2] García de Arquer, F. P., et al., Semiconductor quantum dots: Technological progress and future challenges, Science, 2021, 373(6555), eaaz8541.

[3] Wan, Noel H., et al., Large-scale integration of artificial atoms in hybrid photonic circuits, Nature, 2020, 583, 226–231.

[4] Kaushik, Shuchi, et al., Surface modification of AlN using organic molecular layer for improved deep UV photodetector performance, ACS Applied Electronic Materials, 2020, 2.3, 739-746.

[5] Narang, K., Pandey, A., Khan, R., Singh, V. K., Bag, R. K., Padmavati, M. V. G., Tyagi, R. and Singh, R. *High-quality AlN nucleation layer on SiC substrate grown by MOVPE: Growth, structural and optical characteristics*, Materials Science and Engineering: B, 2022, 278, 115635.

[6] Sartison, M., et al., Scalable integration of quantum emitters into photonic integrated circuits, Materials for Quantum Technology, 2022. 2(2), 023002.

–Kanika Arora and Rajendra Singh
IIT Delhi

Conferences and Events

1. The ElectroTech Expo 2024 is one of the most important India's trade fair for electronic systems, semiconductors, PCBs, and smart solutions industry. The event was took place from 15 to 17 February 2024 at Auto cluster, Exhibition Centre, Pune. The event facilitates smooth exchange of relevant information among participants. With wide global participation, ElectroTech Expo 2024 is an ideal platform to launch new products, focus on safety and networking, discover market trends, explore advanced technologies, and connect with industry leaders. The event also highlights India growing role in electronics manufacturing under an initiatives "Make in India" campaign. The ElectroTech Expo 2024 has overall set a platform for continued growth and development of electronics industry in India. Around 150 technology service representatives are interacted with over 8500 customers face-to-face. The details about the event are given in the website:
https://www.prolim.com/electrotech-expo-2024/.

2. SEMICON INDIA 2024 will be organized by India Semiconductor Mission in partnership with SEMI and industry associations under the visionary leadership of Hon'ble Prime Minister of India Shri Narendra Modi Ji. The aim of the event is to put India as a global hub for semiconductor design, manufacturing and technology development under the theme "Shaping the Semiconductor Future". PM Modi Ji will inaugurate the conference to showcase the India semiconductor strategy. The conference will witness participation from the top leadership of global semiconductor giants and will bring together global leaders, companies, experts of the semiconductor industry. More than 250 exhibitors and about 150 speakers across the global semiconductor supply chain will be expected to participate in the SEMICON India 2024. The event will be co-located with electronica India and productronica India which provides Southeast Asia's single largest platform for showcasing the latest advancements in the semiconductor and electronics industries. The event will offer valuable insights into innovations and trends in key areas such as smart manufacturing, supply chain management, sustainability, and workforce development. The details about the conference are given in the website: **https://www.semiconindia.org/**.

3. International Conference on Semiconductor Technologies–Materials to Chips will be organized by Amity Institute for Advanced Research and Studies (Materials & Devices) and Amity Institute of Nanotechnology at Amity University, Noida, Uttar Pradesh between 18 and 20 September 2024 in association with the Society of Semiconductor Devices (SSD) and Semiconductor Society (India). The conference will organize under the theme to exchange of innovative ideas, research and recent trends in the state-of-art in semiconductor technologies from materials to chip designing. The conference will explore opportunities to collaborate with the top experts from various institutions and industries from the country and around the world. The last date of registration is 10 August, 2024. The details about the conference are given in the website: **https://amity.edu/ICST2024/default.asp**.

Latest News and Updates

1. The researchers in China have reported a development toward UV photonic integrated circuits using III nitride epitaxial layers on Si. The researchers integrated four diodes acting as monitor, LED, modulator, and photodetector coupled together on a level using 50μm wide GaN waveguide. InGaN and AlGaN epitaxial layers were used by MOCVD deposition in a sequence for waveguide and cladding layers. The research work shows a vision for UV microscopy, biosensing, and on-chip data communication. The research team has commented that their integration scheme based on the epitaxial III–V on Si substrate is feasible for realizing a compact, low-cost, and low-complexity photonic integrated circuits system. The III–nitride layers are necessary to access and transmit UV light since Si absorbs such type of radiation. The research team has reported that the photonic integrated circuits chip has potential prospects for audio transmission and sensor applications. [*Jiabin Yan et al., IEEE Transactions on Electron Devices, 71, 5, 3056 (2024)*]

2. Researchers based in CNRS, France and Georgia institute of Technology, UAS have reported on the extension of 2D material based layer transfer to free standing III-nitride MEMS systems on Si substrate. The researcher team used a pick-and-place method to fabricate free standing III-N MEMS structures on Si. III-nitride material was grown on a hBN layer on sapphire and transferred to a micro cavity in a Si substrate. The grow method was MOCVD. The research work has reported two samples. One sample is with 300nm GaN and 300nm AlGaN layers on 3nm hBN. The second sample is with 2.5μm hBN layer. A 15mmx15mm stamp with double sided water soluble adhesive tape on its surface picked the III-N from the growth substrate. The underside of III-N structure was wetted with a water before placing in 22μm deep micro cavities deep RIE into a Si substrate. The stamp was removed by dissolving the tape in a water filled beaker. [*Rajat Gujrati et al., Applied Physics Letters, 124, 104102 (2024)*].