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IEEE Summer School on Nanotechnology

Pioneering a New Learning Paradigm for Post-COVID Education Training on Fabrication and Characterization of Nanomaterials

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IN THE AFTERMATH OF THE COVID-19 pandemic, the landscape of global education has undergone a transformative shift. This has paved an opportunity to conduct a training program on nanotechnology in hybrid mode. The IEEE Summer School on Nanotechnology (SSN) 2022 has emerged as a creative and trailblazing initiative led by the IEEE Nanotechnology Council (NTC). The training program is designed to focus on the intricate domains of nanomaterial fabrication and characterization with offline hands-on sessions and hybrid lab visits and demos. This program equipped individuals to harness the transformative power of nanotechnology

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and illuminated the potential of innovative methods in shaping a progressive future. The program embraces innovation and catalyzes education in an era of adaptability, aligning with multiple – United Nations – Sustainable Development Goals (UN SDGs). This program is co-supported by the IEEE NTC Young Professionals (YPs) and the IEEE NTC Technical Committees on Nanomagnetics and Nanorobotics / Nanomanufacturing. By harnessing the collective wisdom of the nanotechnology community, this initiative goes beyond imparting theoretical insights. In the journey towards a future driven by nanotechnology, the IEEE SSN prepared learners to steer the course of advancements in this dynamic field, and the work reports the summary and the experience.

INTRODUCTION

Humanity has always been interested in how the natural world surrounding us is sustaining in its current state. Throughout history, matter has remained a subject that has captivated minds, from ancient philosophers like Kaṇāda [1] to modern-day visionary physicists like Feynman [2], who even discussed nanotechnology before it was formally coined. Countless researchers have contemplated questions such as: Can we harness the properties of matter by employing innovative approaches and constructing materials at the atomic scale? Throughout our lifetime, we encounter a multitude of materials. In 1959, Richard Feynman delivered a talk titled "There is a plenty of room at the bottom", which serves as the basis for exploring new possibilities in technology using materials of nano-scale dimensions. With our understanding, it is now possible to create materials in small sizes, such as nanoflakes, nanotubes, fullerenes, quantum dots and more [3]. Inspired by the various applications of nanomaterials in different aspects of human life [4], the Institute of Electrical and Electronics Engineers Summer School on Nanotechnology -2022 (IEEE SSN-2022) is designed to gain diversified knowledge in nanoscience and technology by bringing together intellectuals and learners of this field under one umbrella. Earlier to the pandemic, the reach of this knowledge was limited to face-to-face interactions and remained a challenging problem for the widespread technical and scientific aspects of nanomaterials, which is essential for educating young professionals. The new normal in the post-pandemic revived the usage of various secure video conference digital technologies in teaching-learning processes. It enabled young learners, including students and young professionals, to gain knowledge from anywhere at any time. It has been seen recently that such gatherings of scientists, researchers, and students across the globe are culminating [5]. The perspective of NTC is "to advance and coordinate work in the field of Nanotechnology". In line with this perspective, IEEE SSN 2022 was conceived and designed to "create a platform and opportunity for the researchers to share, learn and to gain experience in nanomaterials" through hybrid mode.

The nanomaterials (~ 1-100 nm in size) are unique in their properties due to their quantum confinement and increased surface-to-volume ratio [6]. The field's interest is growing daily due to its emerging novel practical applications. The technical importance and the need for scientific improvements in the area require the training of young scholars and professionals. Most researchers delved into developing new materials using various advanced methods and understanding their structure-property-function-performance relationships. Hence, it is essential to understand the different fabrication methods of nanomaterials, characterizing them to study their properties for functional applications.

Given the background of discussions, inspiring this initiative's outset for YPs, students and researchers on nanomaterials in hybrid mode. This work highlights the knowledge dissemination and the training programs conducted during 16th – 19th November 2022 as part of Training on Fabrication and Characterization of Nanomaterials at VNR Vignana Jyothi Institute of Engineering and Technology, Hyderabad, India (https://r10.ieee.org/nano-yp/summer)[7], [8]. The objective of the SSN is to allow the transfer of technological knowledge from experts to researchers across the globe. The awareness of various nanomaterials fabrication methods with different characterization tools is distributed through SSN. Understanding such techniques is essential for researchers interested in developing new materials with desired properties. Considering the field's interdisciplinary nature, the SSN plans to meet the learners' interdisciplinary expectations in physics, chemistry, and engineering in developing nanomaterials. While the first two days of the training program are intended to highlight different methods of design and fabrication of nanomaterials, the last two days are targeted to emphasize basic characterization techniques that reveal the nanomaterials' structural, thermal, optical, and nanomechanical properties. Eminent speakers with various multi-interdisciplinary expertise also delivered recent advances and applications in this emerging field.

EXPERIENCE AND INSIGHTS FROM THE IEEE SSN 2022

The inaugural session started on the 16th of November 2022, and the program chair explained the objective by introducing the program to the 200-plus (150 IEEE Members and 60 non-IEEE Members) participants. Emphasis on the importance and training module's structure is detailed. Then, the General Chair of the program welcomed the participants and explained the importance of attending such technological sessions. Later, the founding chair, IEEE-NTC-Hyderabad and the chief guests explained the significance of nanomaterials in engineering applications. The IEEE Hyderabad Section Exe-Com has joined virtually and encouraged the participants to utilize the opportunity to explore nanotechnology and improve networking in IEEE NTC. To conclude, the Principal and Director of the institute introduced the participants to the Centre for Nanoscience and Nanotechnology and emphasized membership and leadership development via IEEE SSN 2022.

This IEEE SSN is structured into modules: a) Fabrication, b) Characterization, and c) Applications - blended with offline hands-on training and hybrid lab visits/demos with networking sessions. As a first insight from the SSN, an in-depth

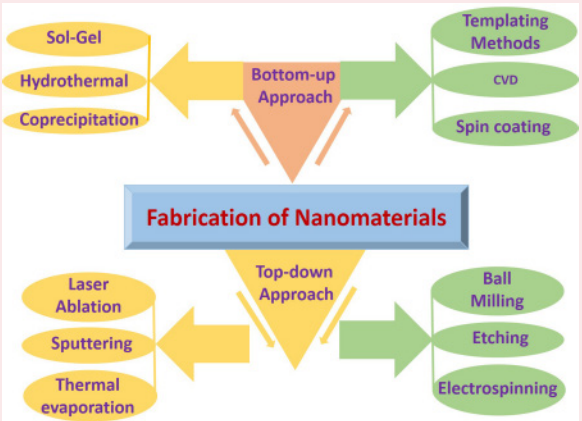

FIGURE 1 A schematic categorization of the bottom-up and top-down approaches for fabrication of nanomaterials as discussed in the IEEE SNN 2022.

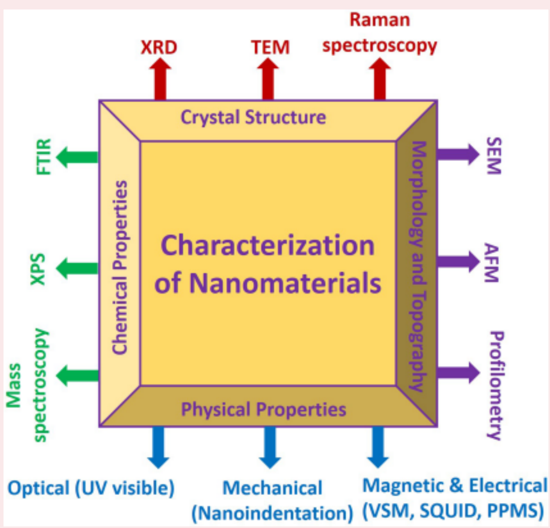

FIGURE 2 A Schematic representation of various characterization techniques for nanomaterials' structural, chemical, physical and morphological properties as presented in the IEEE SSN 2022.

understanding of the module a - fabrication of multifunctional nanomaterials (e.g., Pressure sensors with high sensitivity, utility, and low actuation force; Nanoscale films with water-repellent, antireflective, self-cleaning properties) was given importance to show improvement in the performance [9]. The design of such multifunctional materials allows us to explore new physics, including connections among nanomaterials' mechanical, electromagnetic, and optical properties [9]. Such multifunctional nanomaterials are composites of different shapes with diverse applications [3], [9]. Developing such multifunctional nanomaterials with various fabrication methods for desired properties requires a basic knowledge of approaches, as shown in Figure 1. Under the top-down process, the ball milling method was emphasized. The nanomaterials' hydrothermal, sol-gel, and coprecipitation synthesis befitted the learners and researchers under bottom-up approaches. The basic methodology, controlling parameters, advantages and importance of each fabrication method were discussed. Besides the mentioned methods, thin film nanotechnology- fabrication and thickness measurement were presented for the learners to explore the concepts. To appreciate the importance of the fabrication methods of nanomaterials, III-V semiconductor nanowires materials and devices were discussed to explain their suitability for fabricating nanowires based on their excellent optoelectronic properties [10]. Subsequently, 1D nanowires gained significant attention for next-generation low-cost technology in solar energy harvesters and light emitters. An in-depth understanding of optimizing nanowires' structural and optical properties was presented in detail, attracting the participants of the IEEE SSN 2022.

On the other hand, as part of module b, the nanomaterials synthesized for a particular application must first be characterized by their size, shape, crystal structure and elemental composition, and subsequent days of the program revolved around the primary challenges in analyzing nanomaterials, which include: 1. Measurement of their concentration, 2. Lack of reference materials for calibration, 3. Interdisciplinary nature of the field. [11]. Thus, a comprehensive approach is presented by combining various characterization techniques to find nanomaterials' size, shape, structure and composition. Prominently used experimental techniques XRD, FTIR, UV-Vis, SEM, TEM, and AFM are presented in detail. The SSN allowed the researchers to discuss and understand these techniques, as depicted in Figure 2. The results of characterization techniques help the participants estimate the functional capability and their stability performance as nanomaterials for a specific application [11]. In addition to all the experimental characterization techniques, the IEEE SSN 2022 throws light on the computational methods to study nanomaterials [12], including Density functional theory [13] based molecular modelling, which is used to predict the properties of new materials before synthesizing them experimentally. This approach guides an experimentalist to develop new nanomaterials with desired properties, as discussed and received positively in the IEEE SSN 2022.

ADVANCED NANOTECHNOLOGY FOR EMERGING APPLICATIONS FROM THE SSN ALONGSIDE UN SDGS

In IEEE SSN 2022, alongside the fabrication and characterization, the application of nanotechnology is also discussed as part of module 3 and depicted in Figure 3. The summary of the various emerging applications discussed in the IEEE SSN 2022 follows: Nanotechnology is intertwined with other emerging technologies, such as quantum computing, 3-D additive manufacturing, gene editing, and artificial intelligence [14]. Also, nanotechnology has taken the lead in medicine by improvising traditional drug delivery methods [15]. Notably, the convergence of synthetic biochemistry and nanotechnology allows the generation of novel agents with enhanced resilience for novel drug delivery methods [15]. On the other hand, research shows nanosensors were used to detect toxic pollutants [16]. Also, the electronic industry is revolutionized by minimizing the devices to an unimaginable size. Present and future non-volatile memory devices emphasized switching magnetoresistance nanodevices made of TiO2 for microprocessors. They also find applications in biosensors and human neuro-morphing devices [17]. A distinguished lecture on the Halide Perovskite – memristors for neuromorphic computing explained the role of halides as memristors. They gained significant attention from the participants of the IEEE SSN 2022.

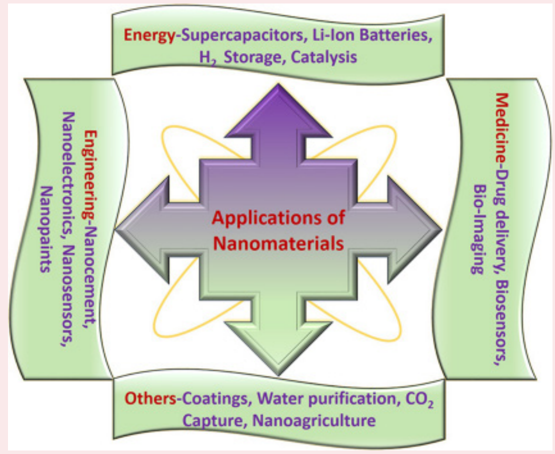

FIGURE 3 Advanced applications of nanomaterials in energy, engineering, medicine and other technological fields as presented in the IEEE SSN 2022.

Not only limited to the presentation of the emerging applications and the road ahead, the "IEEE SSN 2022: Pioneering a New Learning Paradigm for Post-COVID Education" is an educational initiative that aligns with several United Nations Sustainable Development Goals (SDGs) also introduced during the IEEE SSN 2022 and actively reciprocated by the IEEE Member and non-member participants. The UN SDGs in alignment with the program are as follows:

1. Quality Education (SDG 4): The IEEE SSN 2022 provides high-quality education and training in nanotechnology. Offering specialized courses on the fabrication and characterization of nanomaterials contributes to developing skilled professionals who can drive innovation in nanotechnology-related industries in alignment with SDG 4, aiming to ensure inclusive and quality education, promoting lifelong learning opportunities for all [18].
2. Industry, Innovation, and Infrastructure (SDG 9): Innovation and technical development are greatly aided by nanotechnology. People who have received training in the manufacturing and characterization nanomaterials can better contribute to research, development, and innovation in various fields, including electronics, medicine, and materials science. This immediately contributes to SDG 9, concerned with developing resilient infrastructure, encouraging inclusive and sustainable industry, and encouraging innovation [19].
3. Good Health and Well-Being (SDG 3): Nanomaterials, such as drug delivery systems and diagnostic instruments, offer a vast potential to advance healthcare. Training experts in fabricating and characterizing nanomaterials can create more precise and effective medical treatments, improving health outcomes and supporting SDG 3 [20].
4. Clean Water and Sanitation (SDG 6): The processes of desalination and water filtration can benefit from using nanotechnology. Training in nanomaterials can equip individuals with the skills needed to address clean water and sanitation challenges, supporting SDG 6's goal of ensuring access to clean water and sanitation for all [21]
5. Affordable and Clean Energy (SDG 7): Nanotechnology has applications in energy storage and conversion technologies. By educating professionals in nanomaterial fabrication and characterization, the SSN indirectly supports efforts to develop affordable, clean energy solutions in line with SDG 7 [22].
6. Partnerships for the Goals (SDG 17): Collaboration between academic institutions, industry partners, and governmental organizations is crucial for advancing nanotechnology research and its applications. The IEEE SSN fosters collaboration and partnerships among participants, helping to achieve SDG 17, which emphasizes the importance of global partnerships for sustainable development [23].

The IEEE SSN 2022 program aligns with multiple UN SDGs, as shown in Figure 4, by providing education and training in a field with diverse applications. This educational initiative equips participants with the knowledge and skills to contribute to sustainable development and address global challenges.

FRAMEWORK DEVELOPMENT – SSN VIEW – EDUCATION MODEL

Adopting a virtual platform as an engagement tool within this emerging framework is a valuable endeavour to promote innovation and enhance

FIGURE 4 A set of targeted goals of United Nations Sustainable Development Goals (SDGs) impacted during IEEE SSN 2022.

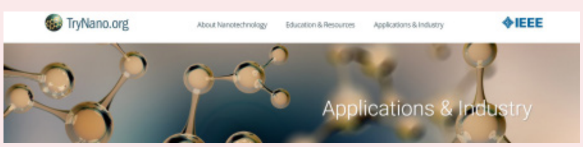

FIGURE 5 The TryNano.org portal developed by IEEE NTC helps the researchers/students/YPs explore the articles, applications, and graphical animations of nanotechnology under one umbrella.

nanoscience education globally [24], [25], [26]. Recognizing the potential of nanotechnology to lead the next industrial revolution and reshape the world, there is a widespread belief that current educational programs for nanotechnology lack competitiveness, necessitating significant paradigm shifts and urgent solutions [26], [27], [28], [29]. Integrating virtual learning environments (VLEs), such as virtual reality, is seen as a stimulating approach for students and instructors, particularly as the incoming nanotechnology workforce is well-acquainted with VLEs [25], [30], [31], [32]. To emphasize the new learning models for the "redefined normal", the participants were introduced to various other models co-existing, such as the- IEEE Around the Clock Around the Globe (AtC-AtG) Conference by the IEEE Magnetics Society [33] and the other active transformative initiative by the IEEE NTC - TryNano. The details on the TryNano Portal were briefly introduced to the IEEE SSN 2022 participants, and they had an opportunity to get hands-on with the portal website. A quick summary is included here as presented during the program: To raise awareness about the significance of nanotechnology education and provide valuable resources for higher learning, the IEEE NTC has created and actively supports the TryNano portal, accessible at https://trynano.org/. For the IEEE's educational outreach initiatives, which cover all sides of nanotechnology, the TryNano portal acts as the focal point (Figure 5). For students, educators, and the general public, it is a priceless resource that enables them to comprehend nanotechnology's foundations and practical applications and investigate career options. In addition, the portal goes beyond providing information by giving students thinking about their future and insightful information about possible career routes. It also includes profiles of scientists and engineers actively influencing the dynamic field of nanotechnology in our rapidly changing world. The participants of the IEEE SNN 2022 appreciated this effort by the IEEE NTC and its usefulness for the workforce.

CONCLUSION

Finally, the IEEE SSN 2022 illustrates creativity and flexibility in the post-COVID educational environment. It is a forward-looking initiative that addresses the challenges of the "redefined normal" and reboots how we approach education in the realm of nanotechnology. By seamlessly blending virtual/in-person lectures with offline hands-on lab sessions, the IEEE SSN sets a new standard for learning, emphasizing the crucial domains of nanomaterial fabrication and characterization. This pioneering effort reflects a global collaboration of expertise. It goes beyond theoretical knowledge, fostering a more profound understanding through practical experience. The objective of the current program is achieved by bringing cutting-edge tech intellectuals together for knowledge sharing and training young minds. The program discussed fundamental principles and characterization techniques in this field, and emerging technologies were spotlighted blended with learning models. Over 200 participants received training over the course of this program. As we venture into a future driven by nanotechnology, the IEEE SSN 2022 equips learners with the skills and knowledge needed to navigate. It is not just a program; it's a catalyst for resilience, adaptability, and transformative progress in nanotechnology education in alignment with the UN Sustainability and Development Goals. This work represents an essential step forward, illuminating the path toward an innovative futuristic model in education and technology.

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