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Sub: Minutes of the 2nd Stakeholder Meeting to discuss the proposal of Indian Institute of Science Bangalore on the establishment of a 2D Material Based Future Semiconductor Technology Centre / Innovation Hub

1. The subject meeting was held on the 21st February 2022 over video conferencing. This was the second meeting in a series of stakeholders' meetings and deliberations required for developing a DPR on said subject.
2. Earlier, IISc was asked by the PSA's office (*Annexure-I*) on the recommendation of the PSA and Dr Saraswat (NITI Aayog) to submit a DPR on their said proposal (*Annexure-II*). Over 180 eminent members from various leading academic institutes of India, Industry experts and invitees from the Office of the Principal Scientific Adviser to the Government of India (PSA's Office), Ministry of Electronics and Information Technology (MeitY), Department of Science and Technology (DST), Department of Space (DoS), Department of Atomic Energy (DAE) and Defence Research and Development Organisation (DRDO) attended the 1st meeting. Over 40 scientists and representatives from DAE establishments (BARC, IGCAR and RRCAT), DRDO labs (DYSL-CT, DYSL-QT, RCI, LRDE and IRDE) and DOS centers (SCL, SAC, URSC and LEOS) attended the 2nd stakeholder's meeting.
3. The meeting started with welcome remarks from Prof. Mayank Shrivastava, Indian Institute of Science (IISc) Bangalore. He gave a brief overview of the initiative and the steps undertaken thus far. He requested inputs from the members from strategic sector / Govt. ministries to make this a successful and sustainable endeavour, on the detailed presentation that was to follow.
4. Mr. Shirish Panda (Scientist 'D', PSA's Office) welcomed this timely initiative from IISc, Bangalore, and assured all support from the PSA's Office. He emphasised that this initiative should lead to setting up a world-class technology innovation hub. He suggested that as 2D materials domain is in a nascent developmental stage, it is imperative for all the agencies to collaborate at the earliest.
5. Subsequently, Dr Vasudeva (Fellow, PSA Office), expressed his agreement with the proposal and provided a brief about the discussions with PSA and NITI

Aayog. He informed that the PSA (Prof. K VijayRaghavan) and Dr. Saraswat (NITI Aayog) has recommended to take-up this initiative as a top priority while accounting for inputs from all stakeholders.

6. Dr. Harald Gossner (Senior Principal, Intel, Germany) provided a perspective from the industry. He provided a brief about the future of 2D technology in the coming years while explaining the enormous possibilities of this technology. He informed that industries like Intel Corp. and TSMC envisions this as the future technology platform of choice and are revamping the manufacturing capabilities in the US and Europe. He shared that Intel is investing over 100B\$ in advanced technology nodes. He anticipates that by 2028 2D materials based electronic/chip products will be out in the market and emphasised the requirement of capacity building in this domain as the highest priority. From the Indian perspective, he emphasised (i) knowledge building in Science & Technology that would lead to a generation of talented future engineers to work in such advanced technological nodes and (ii) technology knowhow and 2D technology manufacturing landscape development, which will encourage leading industries to invest in India in advanced nodes. He further emphasized that this is the right time to build such centres and innovation hubs as the industry is yet to mature in this technology hence there is an ample scope to contribute. But once the technology is matured and has touched the market, one would only be catching up.

7. Prof. Shrivastava subsequently gave a detailed presentation on the proposal and the vision of the proposed 2D technology innovation hub/centre. The 2D Technology innovation hub will facilitate technology development, technology translation, scale-up and product development in the broad field of 2D materials based technologies. The Centre is envisioned to be established as a Special Purpose Vehicle, such as a section 8 company (not an academic R&D centre) catering to the requirements of industry, strategic sectors, academia and start-ups. To facilitate this, the DPR is being prepared with attention to detail. The hub will have a professional structure for execution similar to the corporates. Besides, the hub will self-sustain on its generated revenue after initial 5 years of seed fund with a break-even by 10th year. A detailed operation and revenue model with rough order of magnitude is given in the DPR.

8. He concluded the presentation while emphasising that while the 2D materials-based technology platform will be a crucial enabler for future heterogeneous systems, efforts in India must be scaled up. He added that it is a technology that India can encash only if we get in the game before the technology matures or touches the market.

9. Dr. Aswal (BARC, DAE) emailed (as read out by Prof. Shrivastava) stating that such an important initiative should be taken up immediately. He listed out various technologies that are of key interests to atomic energy and particularly to BARC.

10. Prof. Tarun Sharma (RRCAT, DAE) appreciated the timely efforts and emphasised that the proposal is ambitious, which is the need of the hour with a promising technology roadmap. He briefed about research at RRCAT related to 2D materials and expressed the lack of availability for electronic grade 2D materials and challenges in developing device process/technology. He also added that having access to high quality devices, which is a need of the hour, is highly challenging. Hence, this technology hub might be helpful in solving such roadblocks and give an impetus to future technologies in India. This centre can also help accelerate the critical components required in the strategic sector; that are otherwise often delayed/denied. He suggested building a world-class facility accessible to all stakeholders and catering to everyone's need. He also appreciated the vision of interfacing with industry, academia and strategic sectors.

11. Dr. Padmapriya (URSC, ISRO, DOS) expressed that ISRO would be interested in 2D materials based sensors, heat spreaders, energy harvesting systems, high-density memories, heterogeneous integration in electronic systems, and EMI shielding by Graphene. She appreciated the informative presentation while looking forward to collaborations with the innovation hub on the 2D technology for space applications.

12. Dr Sona Das (Semiconductor Complex Limited) stated that ISRO has several requirements which require 2D material based technology. Some of the devices are THz detectors, IR detectors, sensors, etc. A detailed requirement will be shared soon. SCL has a CMOS fab, and would be keen to collaborate with the innovation hub on developing heterogeneous systems by integrating 2D and Si circuits together – example: while the detectors and sensors can be developed using 2D, the sense/readout circuit can be developed using Si CMOS, all vertically integrated inside the same chip. He stated that this is an excellent initiative and must be taken-up with highest priority.

13. Dr. Brahmananda Chakraborty (BARC, DAE) appreciated the efforts and the presentation made by Prof. Shrivastava. He suggested to also include energy storage devices like 2D materials based supercapacitors, fuel cell devices, and hybrid materials (TMD with MXenes) in the technology roadmap, as these are of key interest to DAE. He also emphasised that the centre must act as a bridge between academia, strategic, industry and start-ups. He shared several other critical requirements from the DAE perspective, specific to nuclear reactors.

14. Prof. Shrivastava informed that the hub will also host computational infrastructure and a small group of computational experts to interface between user lab/industry and academic groups.

15. Dr Sudhir Khare (IRDE, DRDO) complimented the comprehensive presentation of the proposal. He highlighted that optoelectronic and IR imaging (cooled and uncooled detectors) components are of key interest to IRDE. He

emphasised that most IR detectors are imported from Israel and European countries, which are developed using compound bulk semiconductors. He suggested that given 2D material based detectors can outperform those conventional bulk materials, these IR detectors must be added to the technology roadmap proposed. Prof. Shrivastava requested detailed specifications of these products, which will be used to develop the roadmap – being aligned with industry as well as strategic requirements.

16. Shri. Ravindra Prasad (LRDE, DRDO) welcomed the initiative and expressed interest in applications of 2D material based solutions for efficient heat transfer in electronic devices in high power modules for RADAR. They are interested in solutions to reduce the junction temperature, and overall weight of the system. Besides, lightweight EMI shielding is also of key interest.

17. Prof. Sharma suggested that it would be a worthwhile exercise to know about the requirements of the strategic sector that can be taken up for development at the innovation hub from the beginning. Similarly, the innovation hub can also inform the strategic partners about devices possibly in 3-5 years. Prof. Shrivastava welcomed these suggestions and requested for list of devices with specifications that different strategic labs require, which will be included in the DPR and will be used for the technology roadmap.

18. Dr. Selvakumar (DYSL-CT, DRDO) thanked for involving strategic labs at the early stage of the DPR. Although neuromorphic computing, artificial vision is a long-term target, 2D memory-based circuit, 2D based neuron, edge computing sensor, tunable antennas, and electro-chemical sensors are of immediate interest to DYSL-CT.

19. Dr. Selvakumar (DYSL-CT, DRDO) further emphasised the difficulty in getting neuromorphic hardware to test algorithms. He requested that the proposed centre should enable this. He also enquired how strategic sectors and industry will engage with the hub while ensuring requirements of individual company/lab is not leaked with others.

20. Prof. Shrivastava informed that we are working on appropriate IP policies, to be included in the DPR. There will be right MoUs and NDAs in place before getting into any engagement, which would govern the confidentiality issues while clearly defining the boundaries.

21. Prof. B. Gurumoorthy (CEO, SID, IISc) stated that although the modes of operations and collaborations are yet to be finalised, we assure that the centre would foster partnerships between various sectors while protecting everyone's interest and confidentiality. He added that options like collaborative research projects, liaison with the centre for translation, facility usage, and appropriate measures for protecting IP and know-how would be made available.

22. Dr Rajarshi Biswas (DYSL-QT, DRDO) expressed that DYSL-QT is interested in Quantum computing devices/technologies based on 2D materials, especially semiconductor qubits and quantum communications devices. On his enquiry about cryogenic electronics, Prof. Shrivastava emphasised that given 2D TMD based electronics would dissipate lower power, cryogenic electronics operating at sub-4K temperatures are also possible using 2D materials. A long term goal would be to integrate 2D based quantum devices and 2D based cryogenic electronics – a perfect example of heterogeneous integration.

23. Dr Varaprasad (URSC, ISRO, DOS) appreciated the timely initiative and enquired if 2D materials can combat space radiation. Prof. Shrivastava responded that 2D TMDs should be more resilient to radiation when compared to silicon electronics. Thanks to its few atom thick channels, most of the radiation would pass through the 2D channel. He however emphasised that space qualification would be a dedicated topic to pursue. Dr Varaprasad shared several 2D based possible products of interest for space application while emphasising that space qualification or investigations for scale qualification should also be part of DPR. Prof. Shrivastava requested to provide details of products (with specifications), which are of URSC's interest and also to share details of space qualifications.

24. Prof. Sharma concluded the meeting by appreciating the efforts and this timely initiative. He summarised that this initiative must be taken up as the highest priority. He emphasised that if India delays this, we will be again pushed into catching-up mode while suffering from the denial of several critical technologies to be enabled by 2D material based platforms. He requested the participants to complete the feedback form. Prof. Shrivastava thanked everyone for their constructive comments and suggestions.

25. The meeting ended at 1820 hr.
