➢ EDUCATION

Sep. 2014⇨Feb. 2020 Doctor of Philosophy (**Chemical Engineering**), Sungkyunkwan University, https://www.skku.edu/eng/index.do, South Korea.

Jun. 2008⇨Mar. 2010 Master of Science (**Organic Chemistry**), Department of chemistry, Maharaja Krishnakumarsinhji Bhavnagar University, Gujarat, India

Jul. 2005⇨Mar. 2008 Bachelor of Science (**Chemistry**), Sir. P.P. Institute of science, Maharaja Krishnakumarsinhji Bhavnagar University, Gujarat, India

➢ POSITIONS

Mar.2022 ⇨ till date **Marie Skłodowska-Curie Postdoctoral Fellow**, CNRS-INC/LEPMI Lab, https://lepmi.grenoble-inp.fr/en , Grenoble, France.

Website https://cordis.europa.eu/project/id/101026846

MSCA-IF-H2020/Project HOPES (ID# 101026846)

Supervisor Patrice RANNOU (ORCID: https://orcid.org/0000-0001-9376-7136)

CNRS Director of **R**esearch (**DR-CNRS**), **In**stitute of **C**hemistry (**INC**)

Feb. 2020 ⇨ Feb-2022 **Post-Doctoral Fellow (PDF)**, Sungkyunkwan University (SKKU), https://www.skku.edu/eng/index.do, South Korea.

Supervisor Prof. Ho Seok Park (ORCID: https://orcid.org/0000-0002-4424-4037)

PI of the ESEM lab: https://www.esem.skku.edu/

Sep. 2014⇨Feb. 2020 **Ph.D. Candidate**, SKKU, https://www.skku.edu/eng/index.do, South Korea.

Supervisor Prof. Ho Seok Park (ORCID: https://orcid.org/0000-0002-4424-4037)

PI of the ESEM lab: https://www.esem.skku.edu/

Thesis title "Double network gel electrolyte for energy storage applications"

Defense date 11th December 2019

UN SDG N°7 https://sustainabledevelopment.un.org/sdg7

Research overview To overcome the fundamental **trade-off** between **ionic conductivity** and **mechanical, thermal and electrochemical stability** within the know class of gel electrolyte, we proposed here the advanced concept double network based ionogel electrolyte as a cutting-edge alternative solution First by immobilizing the **ionic liquid** to chemically complementary **hard and soft polymer networks**, we demonstrated highly ion conductive, stretchable and ultra-durable double network (DN) ionogel electrolyte. To go a step further this *proof of concept demonstration* and targeting at improving the key performance indicators of this type of key-enabling electrolyte, the **organic hard** network was **replaced** by surface-modified (Silica) **Ormosil-NP network** to form inorganic-organic DN ionogel electrolyte.

Mar.2011⇨Mar.2014 **Project assistant (Level-II),** CSRI-Central Salt and Marine Chemicals Research Institute, Bhavnagar, Gujarat, India.

Project title	Low Energy Membrane Process for Water Separation and Purification
UN SDG N°6	https://sustainabledevelopment.un.org/sdg6
Research overview	I have worked on the preparation, modification and complete characterization of **polymeric membranes** made up of Polyacrylonitrile, Polyether sulfone, Polysulfone and PVDF in **flat sheet and hollow fiber** form for **water purification** applications. I have studied different techniques of membrane fabrication such as spinning, casting and coating. As another major part of this research project, I have carried out surface modification of the Thin Film Composite membranes by surface-**grafting**, **surface coating** using various hydrophilic polymers and **surface interfacial polymerization** to get desired molecular weight cutoff resulting in better fouling resistance and overall functional performances.

➢ AWARDS

Marie Curie Individual Fellowship (ST-EF) : self-assembled/healable Hybrid inorganic/Organic Polymer Electrolytes for sustainable electrochemical energy Storage (HOPES)

Host Institute: UMR5279-LEPMI (CNRS/Grenoble-INP/Univ. Grenoble Alpes)

Project title	self-assembled/healable Hybrid inorganic/Organic Polymer Electrolytes for sustainable electrochemical energy Storage (HOPES)
UN SDG N°7	https://sustainabledevelopment.un.org/sdg7
Research overview	Within HOPES, we will i) develop mechanically, thermally, electrochemically tough self-healable and recyclable SSHEs through the colloidal self-assembly of nanosized building blocks consisting of inorganic core and endgroup (vitrimer functionality)-functionalized Li+ conducting polycarbonate shell: Hairy NanoParticles (HNPs), and ii) establish multi-scale structure/property correlations with advanced characterization techniques at HNP, SSHE, and LMB levels, including synchrotron-based in situ and operando characterizations on operating LMBs. Depolymerization of HNP's organic shell will trigger the disassembly of SSHEs, thereby authorizing the recovery & reuse of inorganic NP cores and (bio-based/sourced) cyclocarbonate monomers, but also the recycling & reuse of (NMC811) cathode and Li° anode to secure critical/strategic minerals and metals.

➢ PUBLICATION

- **ELECTRODE/ELECTROLYTE DESIGN**

1. P. Xiong, Y. Kang, N. Yao, X. Chen, L. Zeng, Q. Dou, X. Han, **H. H. Rana**, Z. Tian, J. H. Park, Q. Zhang, H. S. Park, "*Solvation Structure and Interfacial Regulation for Extremely Stable Zinc Metal Anodes Operating in a Wide Range of Temperatures*" **Applied Physics Reviews**, Accepted 2021. **IF-19.16.**

2. P. Sivakumar, M. G. Jung, C. J. Raj, **H. H. Rana**, H. S. Park, "*1D interconnected porous binary transition metal phosphide nanowires for high performance hybrid supercapacitors*", **International Journal of Energy Research** 45, 17005-17014 (2021). **IF-5.16**. DOI: 10.1002/er.6874

3. M. Jana, J. M. Park, M. Kota, K. H. Shin, **H. H. Rana**, P. Nakhanivej, J-Q Huang, H. S. Park. "*Surface Redox-Active Organosulfur-Tethered Carbon Nanotubes for High Power and Long Cyclability of Na–*

Organosulfur Hybrid Energy Storage". **ACS Energy Letters** 6, 280-289 (2020). **IF-19.05**. DOI: 10.1021/acsenergylett.0c02188

4. Y. Kang, B. Wang, Y. Yan, **H. H. Rana**, J. Y. Lee, J. H. Kim, H. S. Park. "*Three-dimensionally macroporous nitrogen and boron co-doped graphene aerogels derived from polyaspartamide for supercapacitor electrodes*" **Materials Today Communications** 25, 101495 (2020), **IF-2.67**. DOI: 10.1016/j.mtcomm.2020.101495

*The primary aim of these research is to **modify** the surrounding environment of electrode and electrolyte **by chemical modification** to introduce certain functions to manipulate their electrochemical behavior for target specific application**. In these studies I contributed in optimizing the chemical modification strategy and provided active support in chemical characterization of the resultant materials.***

- **PERSPECTIVE ON ENERGY STORAGE MATERIALS**

5. P. Nakhanivej, **H. H. Rana**, H. Kim, B. Y. Xia, H. S. Park, "*Transport and durability of energy storage materials operating at high temperatures*", ***ACS Nano*** 14, 7696-7703 (2020). **IF-14.58**. DOI: 10.1021/acsnano.0c04402

*We present a brief overview of strategies to **design high temperature energy storage devices** with special focus on **ion transport** at electrode and within electrolyte at **elevated temperature**. In this article, I **review** and **write** the **electrolyte part** where I **correlate** the ion **conduction mechanism** in electrolyte with the segmental motion & **glass transition temperature** of their polymer components.*

- **ELECTRODE(S) INTERLAYER(S)**

6. **H. H. Rana**,[‡] M. Jana,[‡] J. S. Yeon, J. H. Park, L. Qing, H. S. Park, "*Interfacially polymerized polyamide interlayer onto ozonated carbon nanotube networks for improved stability of sulfur cathodes*", ***ChemSusChem*** 12, 1-9 (2019). **IF-7.96**. DOI: 10.1002/cssc.201902236. [‡]equal contribution.

***Dissolution** and **shuttling** of lithium polysulfide (LiPS) is a very **serious problem** in Li-S batteries. In this publication **I propose** an innovative **strategy** to **prevent** LiPS **dissolution** to improve the cyclability by fabricating a **thin and porous** polyamide (PA) mask though **interfacial polymerization**. The synergistic **strong electrostatic** interactions between LiPS and polyamide functional groups and **narrow pore** size bulky **LiPS cannot penetrate** the PA mask but Li^+ can, giving us a prolonged cycle stability of **1000 cycles** with **64.2% retention of capacity**: See Figure 2*

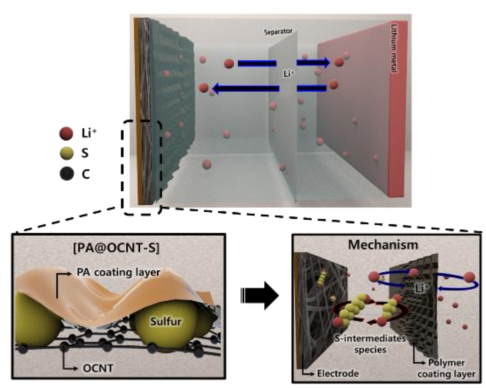

Figure 2. Schematic illustration of the use of a thin PA interlayer for the prevention of polysulfide shuttling.

- **DOUBLE NETWORK ELECTROLYTE STRATEGY FOR ENERGY STORAGE DEVICES:**

7. **H. H. Rana**, J. H. Park, H. S. Park*, "*Highly conducting, extremely durable, phosphorylated cellulose-based ionogels for renewable flexible supercapacitors*", ***Energy Storage Mater.*** 25, 70-75 (2020). **IF-16.28**. DOI: 10.1016/j.ensm.2019.10.030

8. **H. H. Rana**, J. H. Park, E. Ducrot, H. Park, M. Kota, T. H. Han, J. Y. L., J. K., J. Kim, P. Howlett, M. Forsyth, D. MacFarlane, H. S. Park*, "*Extreme properties of double network ionogel electrolyte for flexible and durable energy storage devices*", ***Energy Storage Mater***. 19, 197-205 (2019). **IF-16.28**. DOI: 10.1016/j.ensm.2018.11.008

9. J. H. Park,[‡] **H. H. Rana**,[‡] J. Y. Lee, H. S. Park*, "*Renewable flexible supercapacitors based on all-lignin-based hydrogel electrolytes and nanofiber electrodes*", ***J. Mater. Chem. A*** 7, 16962-16968 (2019). **IF-11.30**. DOI: 10.1039/C9TA03519B. [‡]Equal contribution, research project lead by myself.

*These **three papers** are based on the **concept of double network gel** (the core concept of my PhD thesis: See Figure 3) where gel maintains high toughness even at very high swelled state. Initially, an ionic liquid is confined within a chemically coupled poly(2-hydroxyethylemethacrylate) (pHEMA) and crosslinked PVA (C-PVA) network to realize highly ion conductive, thermally and mechanically durable electrolyte. Later, C-PVA network was replaced with sustainable modified cellulose network. The first two papers are sub-parts (chapters) of my PhD thesis while the **third paper** is based on a similar concept but where the experiments (**carried out by a master student under my supervision)** where relying on lignin-based hydrogel electrolyte combined with carbonized lignin/PAN based electrospun flexible electrode to enable all-lignin based flexible supercapacitor.*

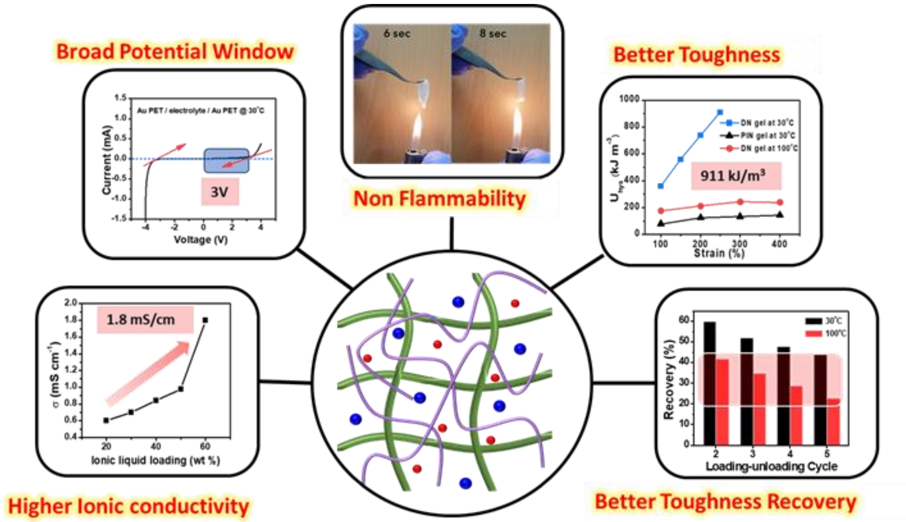

Figure 3. Schematic illustration of Double network strategy and its application improving mechanical, thermal and electrochemical properties of electrolyte

- **DOUBLE NETWORK ELECTROLYTE STRATEGY: AC-FILTERING APPLICATIONS**

10. G. S. Gund, J. H. Park, **H. H. Rana**, M. Kota, J. H. Shin, T-I. Kim, Y. Gogotsi, H. S. Park*, "*MXene/Polymer hybrid materials for flexible AC-filtering electrochemical capacitors*", ***Joule*** 3, 1-13 (2019. **IF-27.05**. DOI: 10.1016/j.joule.2018.10.017

***Rigid shape** Aluminum electrolytic capacitor (AECs) and **lower capacitance** are the two biggest hurdles for high frequency **AC-filtering device**. Here we report flexible ECs that provide high volumetric capacitance and operate in the targeted frequency range of AECs. I developed the **highly ion conducting** and **flexible** hydrogel **electrolyte**, which is highly required for such type of applications.*

- **MEMBRANES**

11. **H.H. Rana**, N. K. Saha, S. K. Jewrajka*, A. V. R. Reddy*, "*Low fouling and improved chlorine resistant thin film composite reverse osmosis membranes by cerium (IV)/polyvinyl alcohol mediated surface modification*" ***Desalination***, 357, 93-103 (2015). **IF-7.09**. DOI: 10.1016/j.desal.2014.11.013

12. S. K. Jewrajka*, A. V. R. Reddy, **H.H. Rana**, S. Mandal*, S. Khullar, S. Haldar, N. Joshi, P. K. Ghosh*, "*Use of 2,4,6-pyridinetricarboxylicacid chloride as a novel co-monomer for the preparation of thin film composite polyamide membrane with improved bacterial resistance*", ***J. Membrane Sci.*** 439, 87-95 (2013). **IF-7.18**. DOI: 10.1016/j.memsci.2013.03.047

13. R. Muppalla, **H. H. Rana**, S. Devi, S. K. Jewrajka*, "*Adsorption of pH-responsive amphiphilic copolymer micelles and gel on membrane surface as an approach for antifouling coating*", ***Appl. Surf. Sci.*** 268, 355-367 (2013). **IF-6.18**. DOI: 10.1016/j.apsusc.2012.12.098

14. K. Parashuram, S. K. Maurya, **H. H. Rana**, P. S. Singh, P. Ray*, A. V. R. Reddy*, "*Tailoring the molecular weight cut off values of polyacrylonitrile based hollow fiber ultrafiltration membranes with improved fouling resistance by chemical modification*", ***J. Membrane Sci.*** 425, 251-261 (2013). **IF-7.18.** DOI: 10.1016/j.memsci.2012.09.013

*The primary aim of these research is to **prepare membranes** and **modify their surfaces** to **prevent cake layer formation** and **chemical degradation** of top **polyamide layer** to achieve higher purification and long-term antifouling property. Here, I worked in collaboration with other lab members to develop different **chemistries** to achieve **smooth and hydrophilic top layer surface** to prevent biomolecule-based cake layer formation.*

➢ PATENT

1. H. S. Park, **H. H. Rana**, J. H. Park, "Gel electrolyte having double crosslinked polymer network and ionic liquid, method of the gel electrolyte, and energy storing apparatus including the gel electrolyte" **Korea Patent**, 10-2018-0048984, 2018 (Granted).
2. H. S. Park, J. H. Park, S. H. Kim, **H. H. Rana**, "Lignin gel electrolyte, method of the lignin gel electrolyte and lignin electrode, and energy storing apparatus including the gel electrolyte" **Korea Patent**, 10-2018-0141869, 2018 (Granted).
3. H. S. Park, **H. H. Rana**, J. H. Park, "Black Phosphorus-polymer solid electrolyte, method of manufacturing the Black Phosphorus-polymer solid electrolyte, and lithium secondary battery having the black phosphorus-polymer solid electrolyte", **Korea Patent**, 10-2019-0053845, 2019 (Granted).
4. H. S. Park, J. H. Park, S. H. Kim, **H. H. Rana**, "Lignin gel electrolyte, method of the lignin gel electrolyte and lignin electrode, and energy storing apparatus including the gel electrolyte " **US Patent**, 10-2018-0141869, 2018 (Granted).
5. H. S. Park, **H. H. Rana**, J. H. Park, "Black Phosphorus-polymer solid electrolyte, method of manufacturing the Black Phosphorus-polymer solid electrolyte, and lithium secondary battery having the Black Phosphorus-polymer solid electrolyte", **US Patent**, 10-2019-0053845, 2020 (Granted).