LVEM 5 Enables Hydrogel Structure-Property Materials Science Research

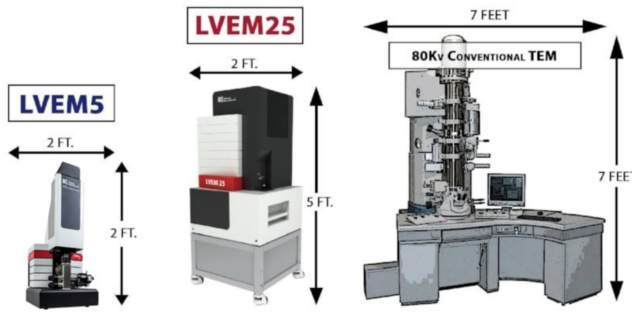
Background

Hydrogels and hydrogel networks enable a broad range of applications through materials science driven understanding of the structure-property-activity relationships of the materials. The central concept is that water soluble polymer units are able to be cross-linked, solidifying into a large insoluble three dimensional structure capable of absorbing large quantities of water. A range of polymers can be employed, with acrylates being a common category. Cross-linking can be driven by physical or chemical means. Physical means can be reversible, and include hydrogen bonds and entanglement of the polymer chains. Chemical means range from free radical initiators to photochemical means, with photo-induced means providing a greater tunability and precision in the extent of cross-linking.

Hydrogel applications include wound dressing and wound gel applications, drug delivery systems, tissue engineering scaffolds, contact lenses and even disposable diapers. Environmentally responsive hydrogels, sometimes called smart gels, are able to sense changes in temperature, ionic strength, and pH and controllably release payloads in response to environmental stimuli. Therefore, with a proven range of commercial applications and a broad range of scientific opportunity remaining, research and development on hydrogels continues to attract significant attention.
This report will survey recent literature on hydrogel research, highlighting both the strengths of the instrumentation and the best approaches for sample preparation methods.

LVEM 5 Characterizes Hydrogels with Antimicrobial Silver Nanoparticles

The LVEM 5 has been utilized to image the morphology of hydrogel networks in order to understand the structure-property-activity relationships of advanced materials. (Rodriguez Nunez, et al., 2019) In this work, various degrees of cross-linking were performed during formation of a hydrogel network. Increasing the weight percentage of cross-linker caused the hydrogels to go from more porous to more filled and smooth morphologies.



The LVEM 5 footprint is 2 ft by 2 ft, compared to 7 feet by 7 feet for conventional TEM.

This in turn affected the formation of silver nanoparticles synthesized within the formed hydrogels, as smaller sized nanoparticles such as ~3 nm were formed in the more cross-linked hydrogel materials. The porosity of the hydrogels also impacted their ability to release antimicrobial silver ions from and through the channels, in combination with the fact that silver nanoparticles of smaller diameters are able to release more antimicrobial silver ions. Ultimately the structure of the materials directly impacts the antimicrobial activity of the materials as measured by a larger zone of inhibition against *S. aureus.*

The LVEM 5 plays a key role in identifying the morphology of the hydrogel networks. By being able to operate in either SEM, TEM or STEM modes, and with the smallest footprint available for this suite of capabilities, the LVEM 5 is powerfully positioned to improve research efficiency in the area of hydrogel structure-property determinations.

Methods:
In the materials and methods section, Rodriguez Nunez et al. describe the method of formation of their

hydrogel, followed by freeze drying to achieve a xerogel. This solid form is then cut and attached to an SEM sample mount. Next, a staining procedure using 0.7% w/v phosphotungstic acid was used, followed by washing and drying of the sample. The LVEM 5 was then operated in SEM mode with a nominal 5kV operating voltage.

This approach yields a hydrogel matrix that is very dark in contrast. The porous parts of the hydrogel matrix become very visible against the dark background of the solid matrix material.

Hydrogels for tissue scaffolding

The LVEM 5 in TEM mode was used in a recently reported is the synthesis of a hydrogel for potential biomedical applications including tissue engineering and drug delivery. (Arokianathan et al., 2020) The LVEM 5 data was used to confirm the fibrous structures of their materials formed in various pH conditions. The authors' approach uses a non-proteinogenic amino acid, 2,3-diaminopropionic acid, as a key part of their hydrogel's molecular structure, to enhance the potential for cell growth and tissue engineering applications.

Methods:
Droplets of hydrogel material were evaporated onto a 300 mesh copper TEM grid, and imaged directly. One opportunity for better imaging can be observed after careful study of this report. The opportunity stems from the choice to use TEM mode and to not wash the grids after preparation. It appears either using SEM mode directly, or washing excess material from the TEM grids can lead to easier to interpret and more beautiful images of hydrogel structures.

LVEM 5 Elucidates Ionic Strength Dependent Structure of nanoGUMBOS

Nanoscale hydrogels have also been studied using low molecular weight gelators. (Das et al., 2012)

The LVEM 5 provides excellent TEM images of the structure varying as a function of the ionic strength of the solution, in this case by increasing concentrations of 25 mM to 500 mM TRIS buffer. The physical cross-linking of the gelators leads to different domain structures, and the LVEM 5's exceptional contrast of carbonaceous materials provides excellent details of the structures shown in the third figure of the publication.

Methods:
A droplet of hydrogel was evaporated onto a TEM grid, allowed to dry, then washed with water to remove the water soluble gelator and leave only the hydrophobic hydrogel materials remaining on the TEM grid after evaporation. The LVEM 5 was used to collect images and determine the average particle size and size distribution properties of the hydrogel materials.

Table 1: Summary of LVEM 5 hydrogel imaging:

REFERENCE	SAMPLE PREP	IMAGING MODE
Rodriguez, et al., 2019	Section from freeze-dried solid, mounted to SEM stub	SEM
Arokianathan, et al., 2020	Evaporated onto 300 mesh Cu grid	TEM
Das, et al., 2012	Evaporated onto 300 mesh Cu grid & washed with water	TEM

Conclusion

Hydrogel materials will continue to be of rich scientific interest with valuable commercial applications in a broad range of industries. The ability to use a benchtop EM for rapid confirmation of nanoscale and microscale structures increases the efficiency of materials science research by enabling rapid collection of structure-property relationship data. Careful selection of sample preparation and imaging conditions, such as washing TEM grids before use or using SEM mode, can lead to dramatic images collected by the LVEM 5. The world's best benchtop electron microscope, the Delong LVEM 5, continues to contribute to this important area of materials science research.

References:

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About the author:

Robert I. MacCuspie, Ph.D., has over twenty years of experience in nanotechnology and materials characterization. Career highlights include leading the team that developed the silver nanoparticle reference materials at the National Institute of Standards and Technology, the first faculty and Director of Nanotechnology and Multifunctional Materials Program at Florida Polytechnic University, and over five years of consulting at the business-science interface from MacCuspie Innovations, helping companies commercialize and educate on technologies to improve human health.