Improving Irrigation Using an IoT System for real-time Soil Moisture Monitoring

***José Payero, Udayakumar Sekaran, Dana Turner, Anna Sarah Hill, Rebecca Davis, Jonathan Croft, Michael Marshall, and Nathan Smith**
Assistant Professor, Clemson University; Research Technician, Clemson University; Research Technician, Clemson University; County Extension Agent, Clemson University; County Extension Agent, Clemson University; Assistant Professor, Clemson University; Professor, Clemson University.

KEYWORDS: Irrigation, Water, Agriculture, IoT, sensors

INTRODUCTION: Previous research has shown that considerable savings in water and energy could be achieved if sensors were used for irrigation scheduling instead of relying on empirical methods and observations to make irrigation decisions (Irmak et al., 2012, Khalilian et al., 2008, Miller et al., 2012). Despite the documented advantages of using soil moisture sensors to schedule irrigation, the adoption of real-time soil moisture data to make irrigation decisions in commercial farming operations has been very limited. Part of the reason for the lack of adoption of soil moisture sensing technology in agriculture has been the lack of affordable monitoring systems to collect and transmit data in real-time. The objectives of this project were to (1) Demonstrate the use of an affordable Internet of Things (IoT) soil moisture monitoring system among commercial farmers in South Carolina, (2) Evaluate the environmental and economic benefits of using the IoT monitoring technology, and (3) Train stakeholders to use the IoT monitoring technology.

METHODS: A three-year project funded by the NRCS-CIG On-Farm-Trial program was initiated in 2020 to quantify and demonstrate the use and benefits of using a new IoT soil moisture monitoring system developed at Clemson University (Payero et al., 2017a, Payero et al., 2017b, Payero, 2020) among commercial farmers. The system uses low-cost open-source electronics, cell phone communication, and Internet of Things (IoT) technologies (International Telecommunication Union, 2013). The IoT system sends data from soil moisture sensors installed on farmer's fields to the Internet in real time. The farmer can see a graphical display of the data using a computer or free cell phone App. The farmer can use this information to make more timely and accurate irrigation scheduling decisions. Each year in 2020, 2021, and 2022, on-farm trials were installed on six commercial farmer's fields selected as prototype fields. These prototype fields were planted to row crops, including corn, cotton, peanuts, or soybeans. In each farm, two adjacent irrigated fields were selected. The farmers were trained to irrigate one of the fields based on the data from the soil moisture monitoring system and a few simple guidelines. They could irrigate the other field following their usual irrigation practice. Watermark soil moisture sensors were installed at four soil depths (6, 12, 18, and 24 in), and data were transmitted to the Internet every hour. Suction lysimeters were also installed at three soil depths (6, 12, 18 in) in both fields to collect leachate and quantify the environmental impact of the two irrigation management practices. Water leachate samples were collected after each irrigation or rainfall event. Relevant agronomic and economic information was also obtained to compare the economic impact of the two irrigation management options.

RESULTS: the results from 2020 and 2021 showed that with few exceptions, the fields irrigated based on the sensor's data had higher net income than the fields irrigated based on the farmer's practice. For example, the combined data for the two years showed an increase in net income of around 11% when irrigation scheduling decisions were based on the sensor data.

CONCLUSIONS: Based on our positive results, there is a need to continue promoting the adoption of IoT soil moisture monitoring technology among farmers. Future efforts should be directed at educating the farmers via Extension activities to demonstrate the benefits of the technology. Future research efforts should also be conducted to develop more affordable and reliable sensing and data communication technologies adaptable to remote rural areas.

A Study of the atypical Heusler Alloy Fe_2 $(V_{1-x}W_x)$ Al

Krystin Ferguson, Ming Yin, Godwin Mbamalu, Timir Datta, and *Aliou Gadjiko
Senior Student, Benedict College, Professor, Benedict College, Professor, Benedict College, Professor, University of South Carolina, Associate Professor, Benedict College

Keywords: Thermal Conversion, Heusler Alloys, Thermoelectric Properties

The Heusler system permits great flexibility in electronic, thermal, morphological, and structural attributes. A typical (full) Heusler compound has a composition XY_2Z; here X and Y are transition metals and Z is a p-block element. Due to nonstoichiometric composition the atypical alloy offers additional tunability. Interestingly random atomic scale substitution concomitant with off-stoichiometric composition affects transport properties. In addition, both thermal and electronic properties can be selectively targeted. For instance, electrical response is sensitive to defects in valency whereas phonon properties are affected by atomic weight disorder. Consequently, thermal conductivity in the quaternary alloy Fe_2 $(V_{1-x}W_x)$ Al, is likely to be impacted by the large variation in the atomic weights of Vanadium (51) and Tungsten (184).

Thermoelectric materials offer a great potential for directly converting heat into electricity and are essential for wide-scale renewable energy application. For efficient conversion high electrical conductivity and low thermal conductivity is desirable. In this work we investigate the influence of synthesis and annealing on transport properties and the thermoelectric figure of merit (ZT) of this material. We will describe experimental details and numerical results on thermal and electrical properties of bulk $Fe_2V_{0.8}W_{0.2}Al$. Briefly, both electrical resistivity and thermal conductivity, and Seebeck coefficient are measured. The implication of our findings will be discussed.

- Heusler alloy, with appropriate substitution V/W was successfully synthesized.
- The atomic analysis shows the presence of all elements of the quaternary compound in polycrystalline form.
- Temperature dependent resistivity decreases, thus revealing a typical semiconductor property.
- Temperature seebeck coefficient (S). shows that S increases with absolute temperature for T> 300K.
- We in the future investigation will focus on temperature control sintering process.
- The Optimization of the experimental parameters is required for technological applications.

This work is partially supported by DOE award DE-NA0004004.

MXene/Microgel Jammed Systems for High Performance 3D Printable Inks and Metamaterials

Farivash Gholamirad, Monirosadat Sadati, *Nader Taheri-Qazvini
Doctoral Student, University of South Carolina, Assistant Professor, University of South Carolina, and Assistant Professor, University of South Carolina

Keywords: MXene, microgel, jamming, 3D printing, metamaterial

Introduction

As smart devices proliferate, protecting sensitive electronics from electromagnetic interference (EMI) grows increasingly critical. Recently emerged 2D transitional metal carbides/nitrides (MXenes) have demonstrated potential for EMI shielding applications owing to high electrical conductivity and ease of processing. However, formulating MXene inks suitable for scalable additive manufacturing of EMI shields remains constrained by intensive processing requirements and high solid content. Here, we pioneer a strategy to induce the jamming of polymer microgels to template ultra-low concentrations of percolated MXene, overcoming these existing formulation barriers. This enables customized solid-state metamaterials by tuning MXene dispersion in the confined microgel morphology.

Methodology

MXene nanosheets were synthesized by selective etching and used alongside polymer microgels to prepare aqueous inks with total solid content as low as 2 wt%. Polymer microgel jamming confines MXene while enabling network percolation, achieving viscoelastic properties surpassing existing 3D printable MXene inks. The ink's shear-thinning capacity facilitates printing complexity without nozzle clogging or filament spreading. 3D structures were printed via extrusion and freeze-dried into aerogels with properties contingent on MXene dispersion tunable by microgel size and *p*H. Morphology was examined across length scales by electron microscopy and X-ray scattering. Rheological measurements provided insights into microstructural developments. Electromagnetic shielding effectiveness and mechanical response were evaluated to elucidate structure-processing-property relationships.

Results

The optimized MXene/microgel ink manifests exceptional rheological properties, including viscosity exceeding 50,000 Pa.s and yield stress around 400 Pa despite containing only 2 wt% solids. This is enabled by jammed microgel confinement of percolated MXene networks with high storage modulus, facilitated by favorable hydrogen bonding between the nanosheets and polymer chains. The ink's shear-thinning capacity allows smooth extrusion without nozzle clogging while rapidly recovering post-deposition to retain shape fidelity of complex printed architectures.

The printed structures maintain dimensional stability during freeze-drying, morphing the hybrid ink into MXene-based metamaterial aerogels with 99% porosity. The dispersion state of MXene throughout the microgel template can be tuned by varying *p*H and microgel crosslinking, providing control over the solid-state properties. The aerogel combining 0.24 vol% MXene and microgel particles optimized for 3D printability delivers exceptional conductivity of 360 S/m and electromagnetic shielding effectiveness, reaching 57 dB across X-band frequencies.

The ultra-low density 25 mg/cm^3 aerogel can support over 5,000 times its weight with 1750 kPa compression modulus despite possessing 99% air. This mechanical robustness demonstrates the load-bearing capacity imparted by the reinforced cell walls constructed from percolating high-modulus MXene networks. The collective advantages directly result from the synergistic melding of components enabled by microgel-guided assembly, overcoming conventional tradeoffs.

Conclusions

The jamming of polymer microgels can template percolated MXene networks at ultralow concentrations, transcending formulation barriers to 3D print multifunctional metamaterials. By elucidating the complex interplay between MXene, microgels, and polymer chains, an interrelated morphological parameter space emerges, enabling systematic property optimization for diverse functionality goals.