Conductive Ink Meets Spider Silk

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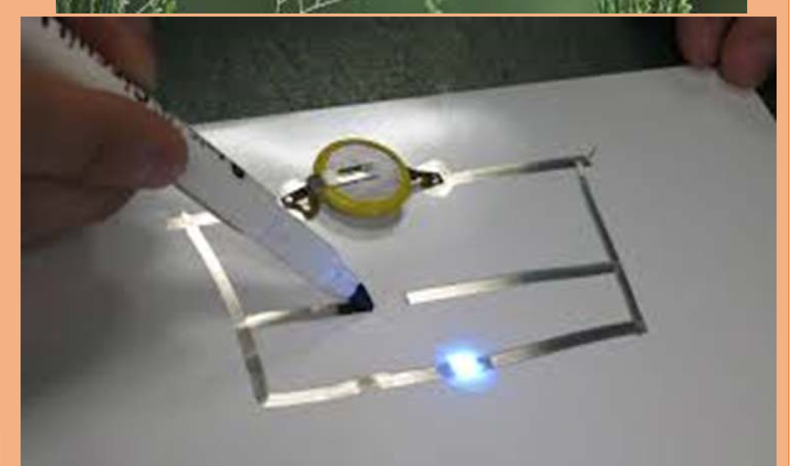
Introduction

Spider silk proteins can be created synthetically and are highly valued for their strength, durability, and flexibility. By altering the genome of goats, silk worms, and the bacteria *E. coli* we are able to manufacture spider silk products in lab. The production and manipulation of these 'recombinant spider silk proteins' along with the process of aqueous solubilization can yield many useful spider silk materials such as films, fibers, gels, coatings, and more. Conductive ink is a recent and popular scientific discovery that let's you create flexible working circuits. This product has many applications including RFID tags, circuit boards, and printers. However, most conductive inks contain a highly toxic organic compound known as butanone along with a conductive salt. Our research is to prove that replacing butanone with spider silk proteins in conductive inks will still create a flexible and durable circuit without the toxicity. This non-toxic conductive ink could prove useful when applying the circuit directly into living systems. We also think that using spider silk proteins in our circuits will improve the durability and elasticity of the circuits created.



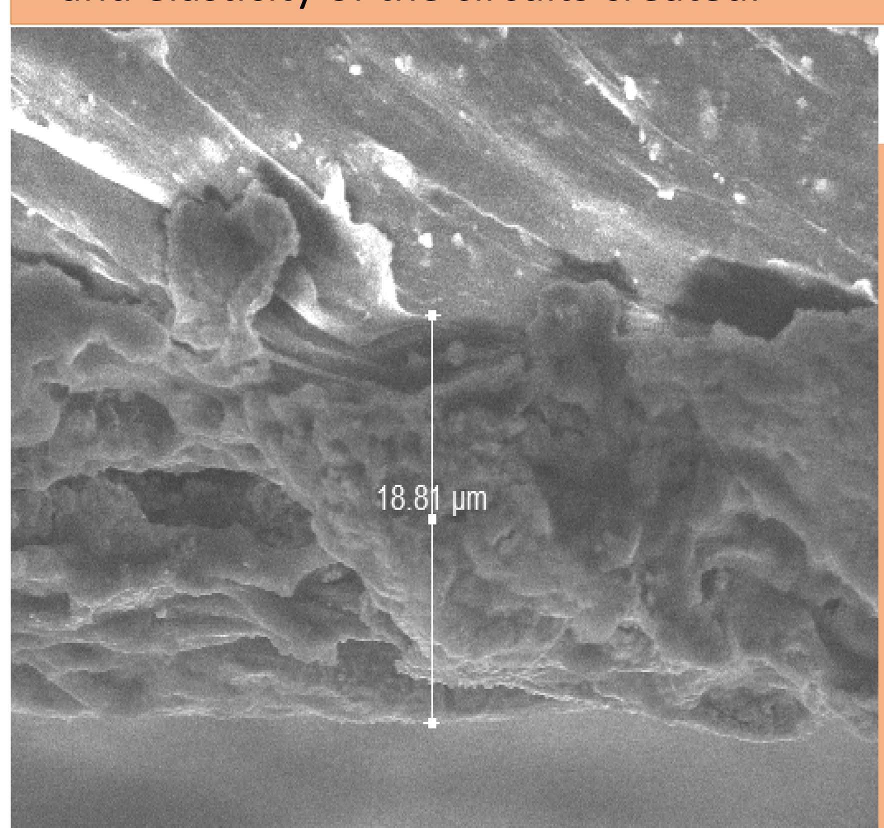


Figure 2: SEM image of Ag-TFA + Spider Silk. Thickness of ink is 18.81 micrometers. Ink thickness directly relates to conductivity.

Methods

A set of substrates were prepared to test the conductive ink on, including PET (Polyethylene Terephthalate), Spider silk film, latex gloves, rubber, and SIS (Styerene-Isoprene-Styrene). These substrates were all cut into uniform shape and size. Their length, width, and thickness were then measured for future tensile strength tests. A number of conductive inks were then prepared, along with a spider silk protein solution, to spray over the substrate surfaces. Once the substrates had been prepared properly, a number of tests were performed including FT-IR (Fourier Transform Infrared) testing, SEM (scanning electron microscopy), and conductivity testing.

Spider Silk Solution Preparation: Through a process already established in the spider silk lab, proteins known as recombinant spider silk proteins (rSSPs) were purified into a fine powder from the milk of transgenic goats. The specific proteins used in this experiment are known as M4 and M5. An 80/20 mixture of M4 and M5 were added to 3 mL of water (5% protein to water mix). This solution was then sonicated for 3 min at 1 amp, sonication helps homogenize the mixture and creates smaller particles. After sonication, the suspension had to be heated in a microwave oven in 5 sec. intervals until a temperature of 250 degrees was reached in order to solubilize the proteins.

Conductive Ink Preparation: In order to prepare the inks with Ag-TFA (Silver Trifluoroacetate), 700 mg of Ag-TFA was dissolved into butanone for one sample and 700 mg Ag-TFA was dissolved into the spider silk solution (as prepared above) for the other. 14 mg of liquid SIS was then added to each of these mixtures. A similar procedure was performed to create inks with CNT (Carbon Nanotube) and AgNO3 (Silver Nitrate). Four different inks were created in all. To finalize the silver salt containing inks, a post-treatment was performed using formaldehyde and sodium hydroxide to pull out the excess silver.

Application of Ink to Substrates: All four of the inks were sprayed onto the five different substrate surfaces using an airbrush for further testing of infrared spectroscopy (FT-IR) and tensile strength. All four of the inks were also added to a syringe in order to produce straight orderly lines of ink on each substrate for further testing of scanning electron microscopy (SEM) and conductivity.

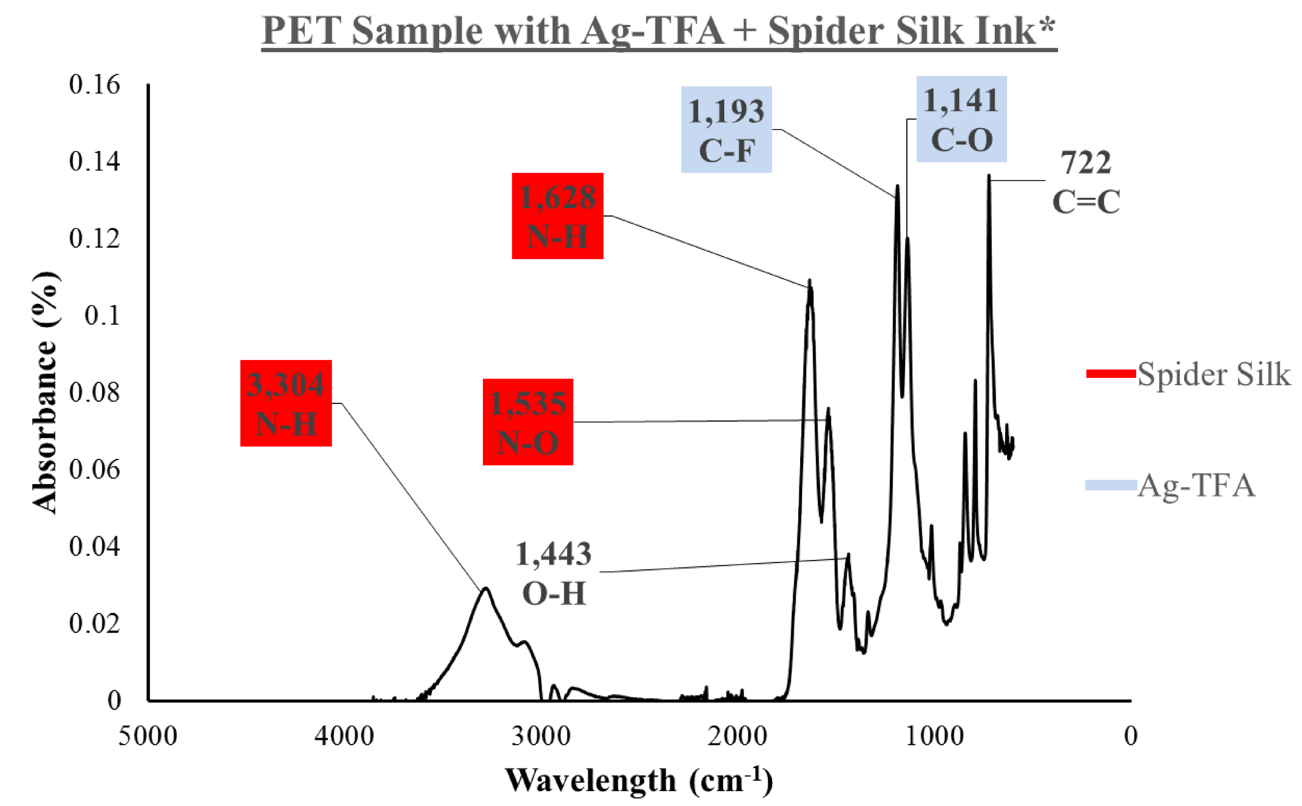


Figure 1a: **Infrared spectroscopy proves the presence of spider silk (N-H/N-O bonds) and Ag-TFA (C-O/C-F bonds). *A Conductive Ink**

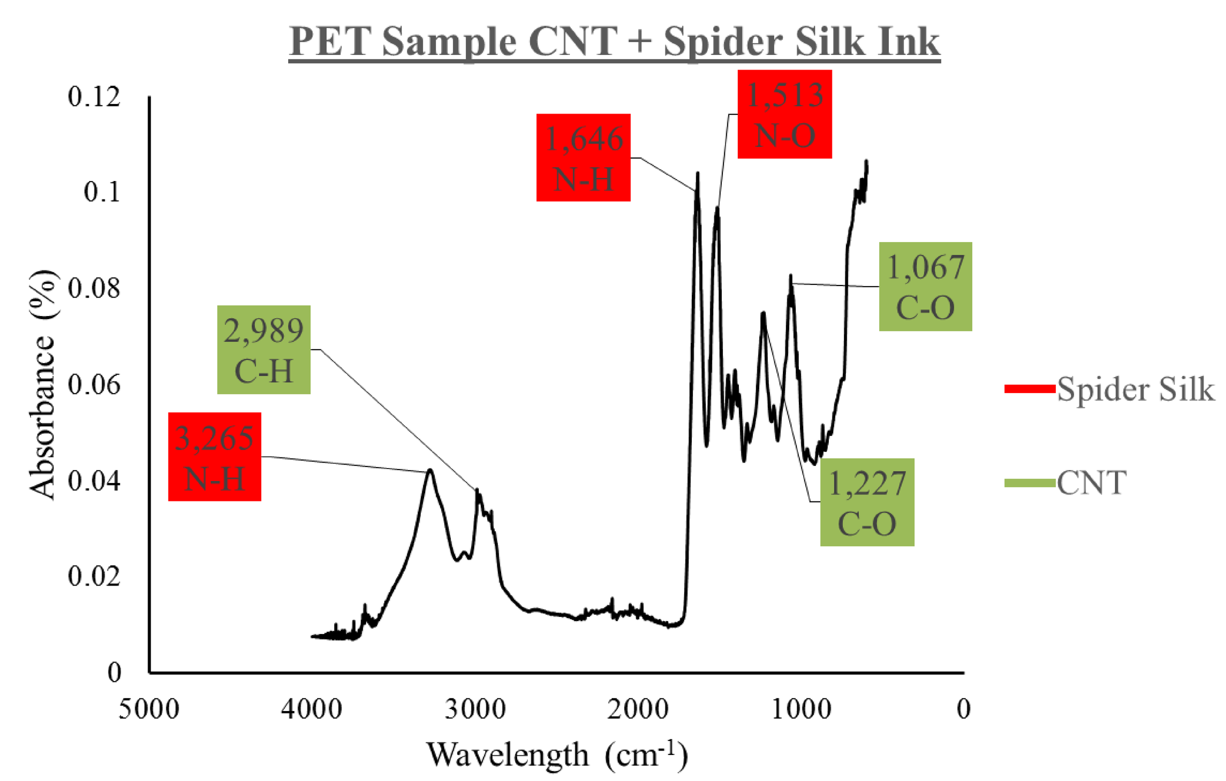


Figure 1b: **Infrared spectroscopy proves the presence of spider silk (N-H/N-O bonds) and CNT (C-H/C-O bonds). *Not A Conductive Ink**

Results

FT-IR: The Infrared spectroscopy confirms the presence of both spider silk and silver salt in the conductive ink. In **figure 1a** the N-H bonds and the N-O bond in this sample are indicative of the presence of spider silk proteins while the C-F and C-O bonds are indicative of silver trifluoroacetate being present. In **figure 1b** the N-H and N-O still confirm the presence of spider silk, but without the silver salt bonds, this sample is not conductive.

SEM: Figure 2 shows an ink sample of Ag-TFA plus spider silk which has been extremely magnified. Generally, ink thickness and conductivity have a direct relationship. This particular sample was indeed conductive.

Conductivity: The table in **figure 3** describes how conductive certain samples were. Conductivity was measured in Mega ohms and is indicated by the letter "R".

Substrate=SIS	Conductive	Details
Ag-TFA + Butanone	YES	R Substrate >200 Mohm Avg. R= 1 Mohm
Ag-TFA + Spider Silk	YES	R Substrate >200 Mohm Avg. R= 1.67 Mohm
Ag-NO3 + Water	NO	*Past studies suggest this should have been conductive, but was not in our project.
CNT + Spider Silk	NO	When applied to surfaces, this ink was not conductive

Figure 3: Shows the conductivity of all four inks applied to one substrate (SIS). Three ink lines were applied directly to the substrate and the average conductivity (Avg. R) is reported above.

Conclusion and Future Work

As discussed above in the results and figures, spider silk can replace butanone and still be conductive in the ink with Ag-TFA. Additionally, the final ink product showed traces of both the silver salt and the rSSPs (see figure 1a) and had a thickness sufficient for conductivity (see figure 2). In some instances, the spider silk ink had a slightly higher average conductivity than the butanone ink (see figure 3). The difference in substrates seemed to play a role in overall conductivity as well, with the SIS samples aiding to conductivity the most and rubber aiding the least. With all the possible variations in shape and complexity of spider silk products, it appears it could be a very useful addition into conductive inks. Especially being non-toxic, it could potentially be used inside living systems like humans. Future work with this project could include testing the conductive inks in actual ball point pens and measuring the conductivity after multiple writing –reduction cycles. Also, MTS (material tensile strength) tests could have been performed on the conductive inks with spider silk to prove whether spider silk conductive ink was more flexible and durable than conductive ink with butanone.