

An Environmentally Friendly Conductive Ink Made Using Transgenic Spider Silk Protein and Silver Salts

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II. Abstract

The goal of this study was to demonstrate that it is possible to formulate an electrically conductive, stretchable and environmentally friendly ink or coating. This is made possible by harnessing the properties of biomimetic spider silk obtained from transgenic goats.

In this experiment we formulated four inks using spider silk, silver trifluoroacetate and carbon nanotubes (CNT). We utilized Polyethylene terephthalate (PET), spider silk, natural rubber (Latex) and polystyrene-block-isobutylene-block-styrene (SIS) as substrates to demonstrate the flexible nature of the ink/coating.

We then conducted surface characterization using FTIR and SEM to verify the presence of our coating and quantified the thickness of our coatings. We measured the conductivity of the ink using an Ohm meter.

Our preliminary results indicate successful formulation of an ink that meets the parameters described above. Inks formulated using spider silk and AgTFA are in fact more stable and conductive than other inks tested in this experiment. We also found little or no success with the other three inks described in the experiment. This study serves as a proof of concept and starting point for optimization of such inks for use in the bio medical and technology sectors.

I. Introduction

For hundreds of years humans have been justifiably fascinated and intrigued by spider silk and the novel properties it offers. Some spiders can produce up to six different kinds of silk with different properties and functions(Figure.1.E).

Unlike other species such as silkworms, which are regularly farmed for their silk, spiders are territorial and cannibalistic which makes farming impossible. Because of these limitations we produce spider silk using transgenic *E.coli* and goats(Figure1.A). Thanks to the efforts of the USTAR team we are able to produce 8 natural and synthetic variants of spider silk using transgenic organisms.

We recognize spider silks for being extremely strong, elastic, biologically compatible, customizable and electrically conductive. This project focuses on the electrical properties of spider silk which offers promising solutions for the development of biocompatible conductive coatings and inks.

Conductive inks and coatings make a variety of innovative technologies possible which include, but are not limited to, biologically implantable chips, sensors and circuitry, flexible electronics, wearable electronics and electronic tattoos with embedded sensors.

III. Methods

Chemicals used:

Polyethylene terephthalate (PET), vulcanized rubber, latex gloves (latex), Polystyrene-block-polyisoprene-block-polystyrene (SIS, styrene 22 wt %), Carbon nano tubes (CNT), silver trifluoroacetate (99%, AgTFA), butanone (≥99.0%), chloroform (≥99.9%), formaldehyde and sodium hydroxide (2M).

Inks:

Spider silk, silver trifluoroacetate:

80:20 ratio of MaSp1, MaSp2 Spider silk protein was weighed and combined with 3mL of DIH₂O. The resulting mixture was then sonicated using a micro sonicator for 3 minutes to breakdown large pieces of protein.

To solubilize the protein the suspension was heated in a sealed vessel using a microwave oven to 130°C or until desired clarity was achieved.

The resulting solution was centrifuged for three minutes at room temperature to remove impurities in one mL micro tubes. In the final step of ink preparation; 10 wt% silver trifluoroacetate (99.9%,AgTFA) was added to the silk solution and sonicated for three minutes to ensure optimal dispersion of silver trifluoroacetate in the solution. The resulting ink was then sprayed using an airbrush and syringe on to SIS, PET, rubber and latex.

Silver trifluoroacetate, butanone, SIS

AgTFA 0.1wt% and 0.002 wt% SIS were combined with butanone in a glass vial and placed into a test tube rotator for 24 hours to dissolve. The resulting ink was then sprayed using an airbrush and syringe on to SIS, PET, rubber and latex.

Spider silk, CNT

80:20 ratio of MaSp1, MaSp2 Spider silk protein was weighed and combined with 3mL of DIH₂O. The resulting mixture was then sonicated using a micro sonicator for 3 minutes to breakdown large pieces of protein.

To solubilize the protein the suspension was heated in a sealed vessel using a microwave oven to 130°C or until desired clarity was achieved.

The resulting solution was centrifuged for three minutes at room temperature to remove impurities in one mL micro tubes. In the final step of ink preparation; we added 0.125 wt% CNT.

Post treatment:

AgTFA-spider silk and AgTFA-Butanone were treated with NaOH(2M) and formaldehyde to precipitate silver.

Figure 1.

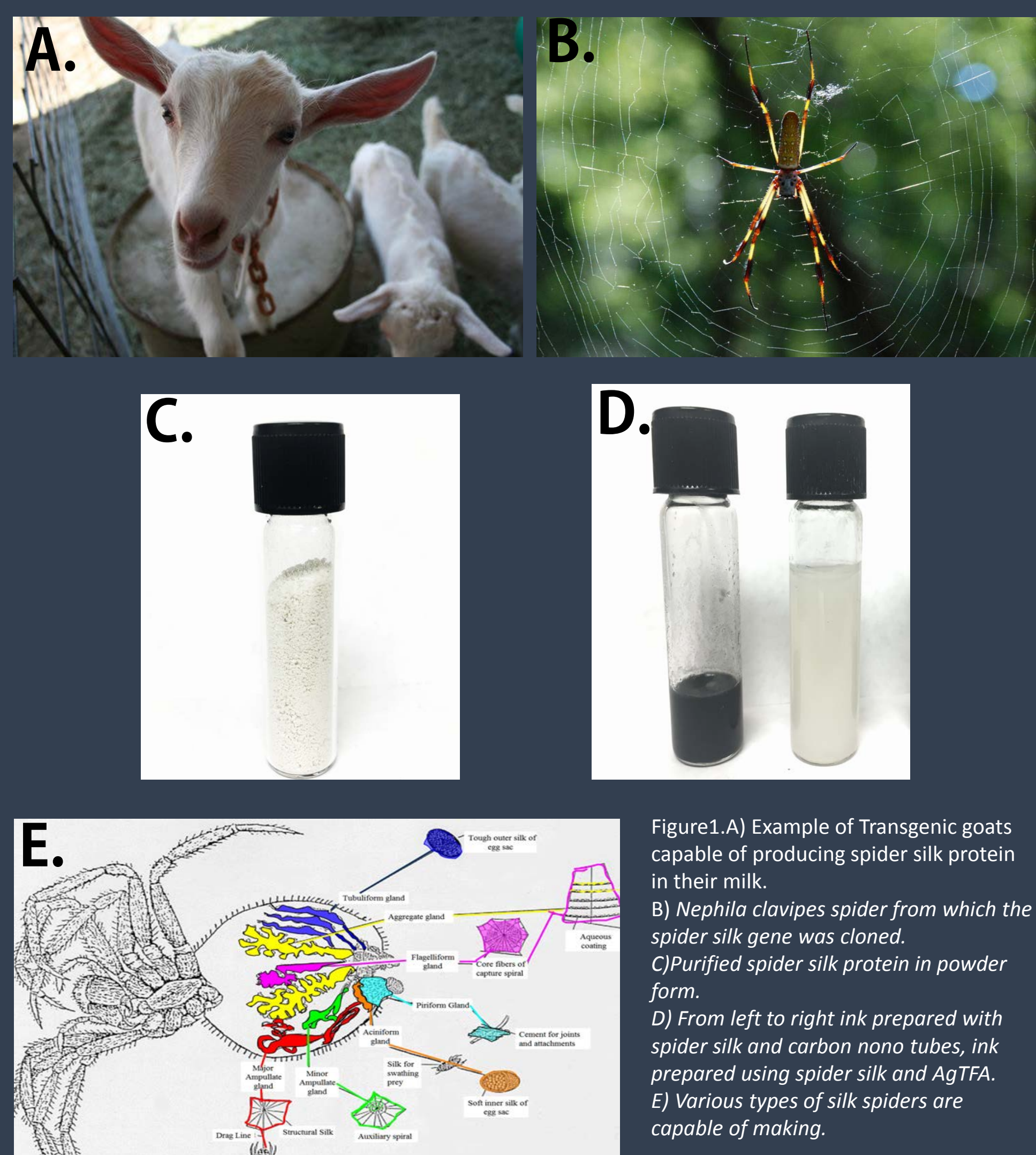


Figure 2.

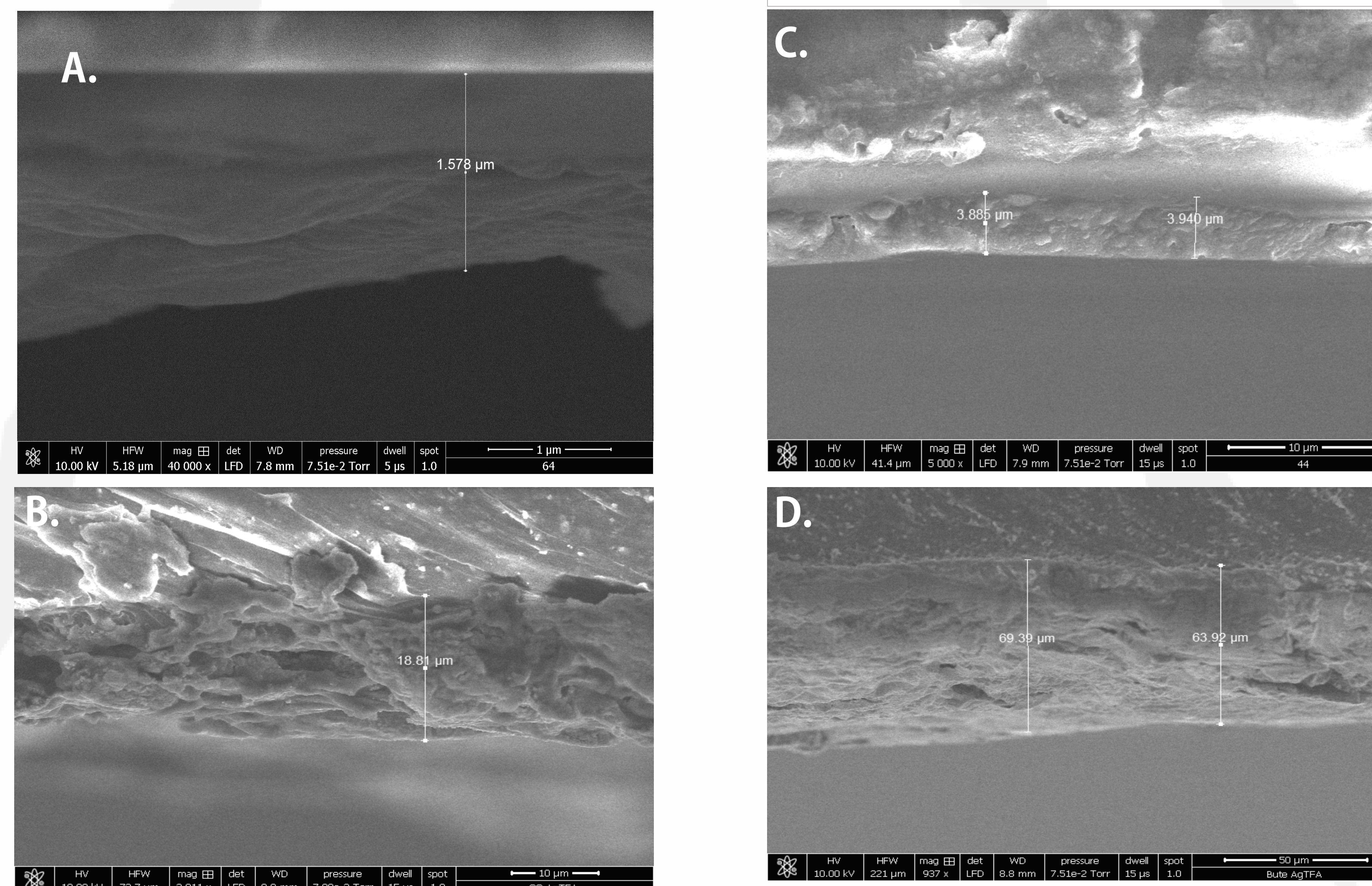
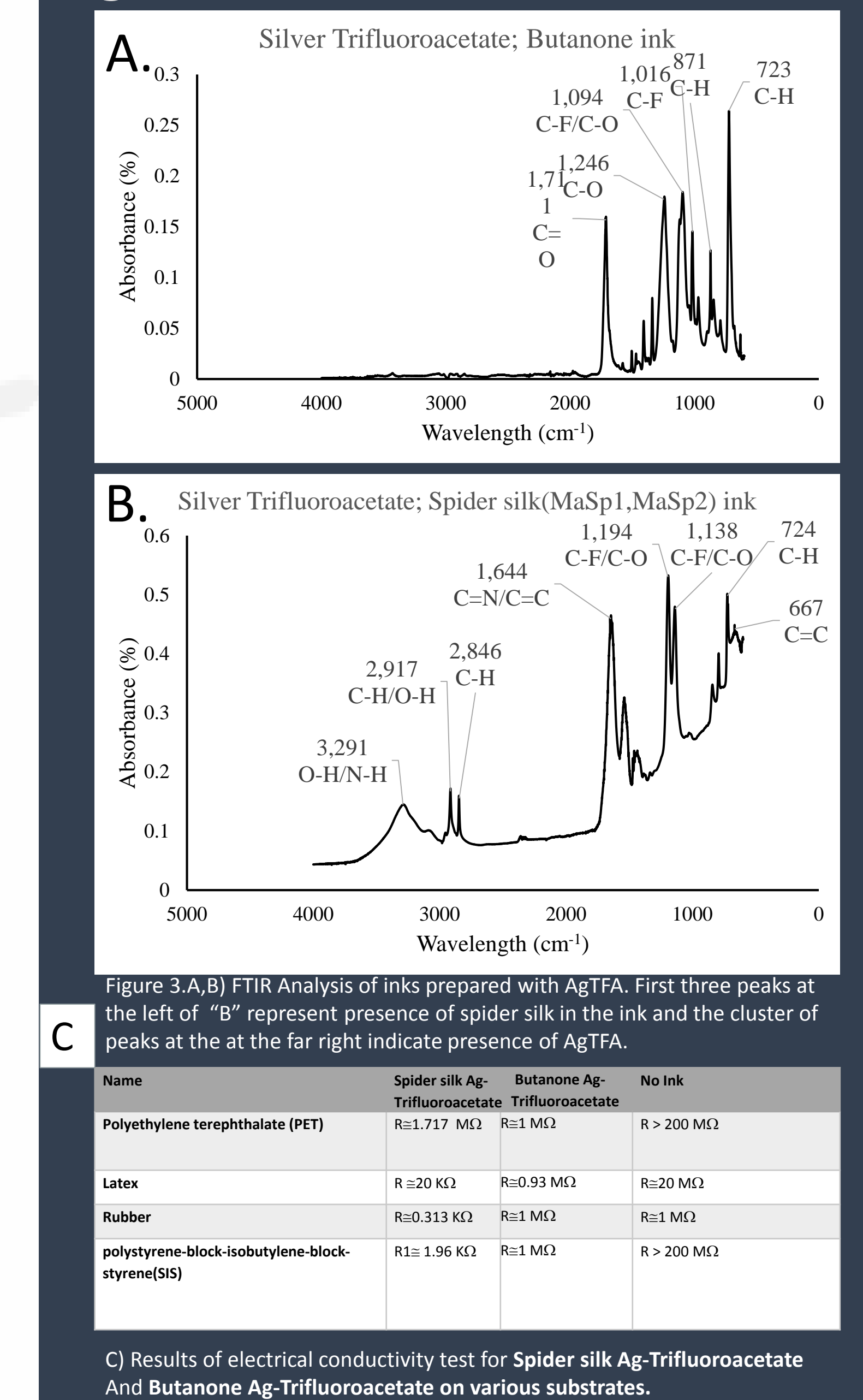


Figure 3.



IV. Results and Conclusions

- The ink formulated using AgTFA and spider silk demonstrated higher stability and electrical conductivity relative to the ink prepared with AgTFA and Butanone. This result is highly promising because spider silk is biologically compatible, innocuous and environmentally friendly whereas butanone is a toxic organic compound.
- Electrical conductivity for AgTFA-spider silk and AgTFA – Butanone are summarized in Figure 3.C.
- Presence of AgTFA and spider silk are demonstrated in Figure 3.A and Figure 3.B.
- Scanning Electron microscopy(SEM) images demonstrate a coating with thickness of 1.6 microns for the sprayed(Figure 2A) on sample of AgTFA-spider silk and 18.8 microns for the drawn sample(Figure 2B).
- SEM images for AgTFA-Butanone show a thickness of 3.8-9.8 microns for the sprayed sample(Figure 2C) and 63.4-69.4 microns for the drawn sample(Figure 2D).
- Inks that used CNTs were found to be non-conductive.
- All inks demonstrated some degree of elasticity.
- With optimization spider silk can replace organic substances such as butanone in conductive inks and add the benefit of being ecologically friendly.