Nanostructured Nickel Electrode using Tobacco Mosaic Virus

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Abstract

Microbatteries are essential in MEMS devices for energy storage and power generation. In this project, a nanostructured nickel electrode using Tobacco Mosaic Virus (TMV) is investigated. The use of the TMV helps to increase the surface area of the nickel electrode, which allows more reactions to take place in the cell, and hence improves the battery performance. The goal in the project is to optimize the current three-day-step process into a more efficient time frame. This work is expected to assist the existing process for the development of MEMS virus-based batteries.

Introduction

In miniaturized systems such as MEMS devices, there is a need of batteries at the microscale level. Thus, comes the challenge of available electrode area, which limits the performance of the battery. The microbattery introduced in this project incorporates a viral structure, Tobacco Mosaic Virus (TMV), which is integrated in the cathode. This TMV based microbattery showed a six-fold increase in capacity compared to batteries with planar nickel electrodes. During the testing with the potentiostat, during the first cycles, the capacity was 1.22μAh/cm² and reached 4.45μAh/cm² at the 30th cycle.

In the realization of technologies, not only the cost of materials is important, but also the time required to manufacture is crucial. In this case, the normal time required for the biofabrication using TMV requires two overnights, which limits the compatibility of this process with the MEMS manufacturing standards. The focus of this work is the optimization of the self-assembly and coating process with the TMV. Fig.1 shows a diagram of the microbattery.

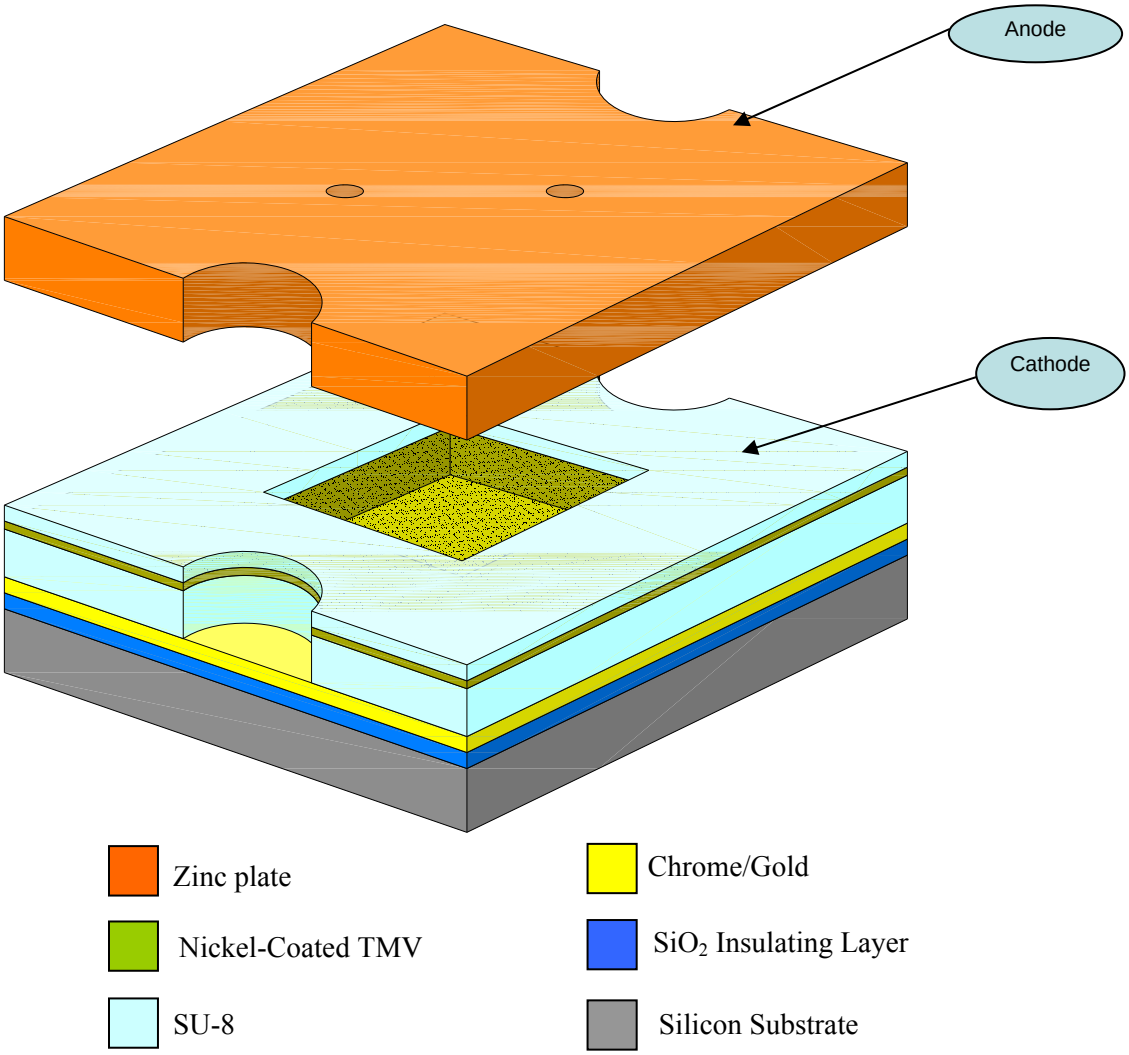


Fig.1: diagram of microbattery

Tobacco Mosaic Virus

Tobacco Mosaic Virus is a high aspect ratio cylindrical plant virus encountered mostly on tobacco plants. It is 300nm long, has an 18nm inner diameter and 4nm outer diameter. Fig 2 shows a clear diagram of the TMV.

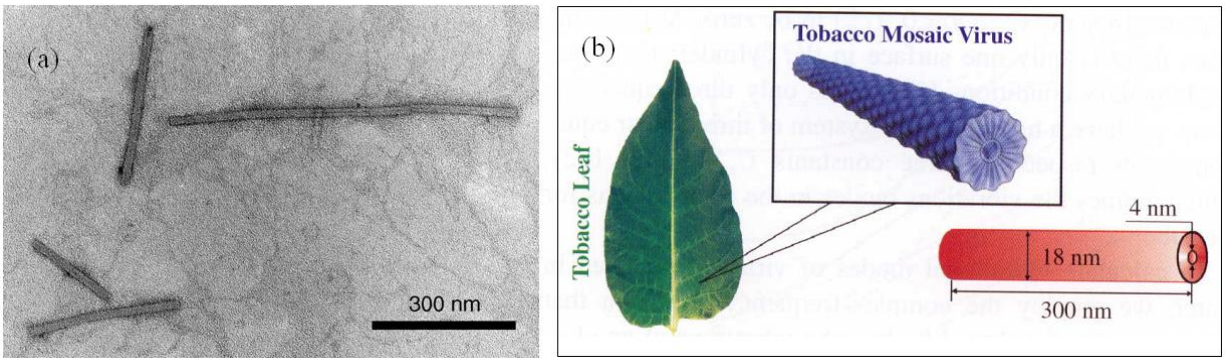


Fig2: a) *TEM image of wild-type viruses* b) *Simplified model of TMV structure*

One reason why TMV was chosen for this microbattery is because they are renewable in large quantities since they are easily accessible from the tobacco plants, and they do not require complicated and expensive technologies to synthesize them. In addition, TMV can be modified by inserting a cysteine (an amino acid containing a thiol group) in its protein coating to become TMV1cys; the thiol groups contributed by the cysteine cause the TMV to self assemble onto the gold surface via gold-thiol interactions. Another reason is that TMV resists temperatures up to 60˚C and pH levels from 2-10.

TMV Self-Assembly and Coating Process

The TMV self-assembly and coating process are solution based reactions that take three steps. In the first step, the gold surface is immersed in a TMV solution during an overnight step; at this point the viruses self assemble on the substrate through the bottom end. During the second step, the virus surface is activated with a palladium catalyst. Through the last step, the surface is immersed in an electroless plating solution and nickel is reduced at the palladium catalyzed sites. A schematic of the process is shown on fig3.

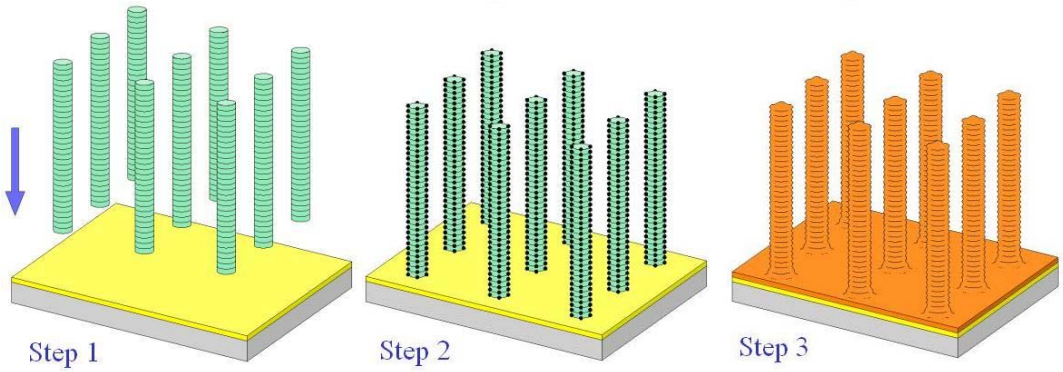


Fig3: step1) TMV bind onto the gold surface, step2) TMV are activated with a palladium catalyst for the electroless plating deposition. step3) Surface is coated with nickel

A gold surface is cleaned in a 1:1 mixture of acetone and ethanol in an ultrasonic bath for 10 minutes. Then the surface is rinsed abundantly and carefully with deionized water and dried. After drying the gold chip, it is incubated in a 0.1M of TMV solution for an overnight.

After spending an overnight in a TMV solution, the gold chip which now contains TMV on its surface, is immersed in a 1:10 mixture of phosphate buffer and sodium tetrachloropalladate (NaPdCl4) solution for another overnight. Palladium serves as a catalyst for the electroless nickel plating.

Finally, the gold chip is transferred from the palladium solution to a 1:1 mixture of nickel solution and deionized water. During this reaction, hydrogen is released and the gold chip is turned dark. The chip is later dried and ready to be imaged.

Methods and Materials

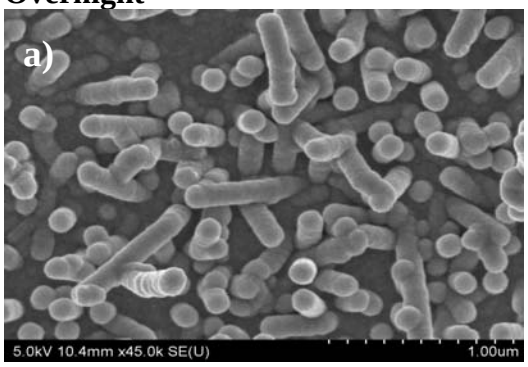
The methodology chosen was to vary the incubation time of the gold chip in the TMV (step 1) while keeping step two unchanged and letting the virus coated gold chip in the Palladium solution (step2) for smaller amounts of time and keeping step one unchanged.

A very important tool used was the Scanning Electron Microscope (SEM) from the NISPLab used to take images of my species. On the images obtained, a particle count was done per μm² section area to characterize the samples.

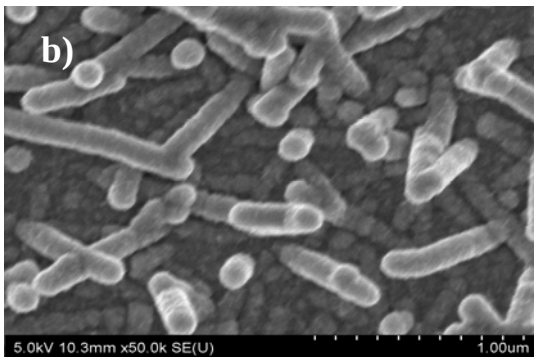
Results and Discussion

Below are SEM images of a virus-coated gold surface immersed in the Palladium solution for an overnight, 2 hours, 5hours, and 8hours.

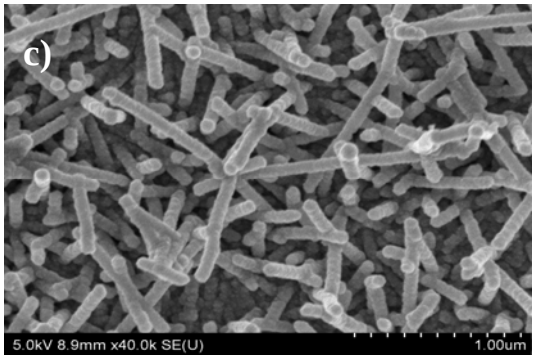
Overnight



2hours



5 hours



8hours

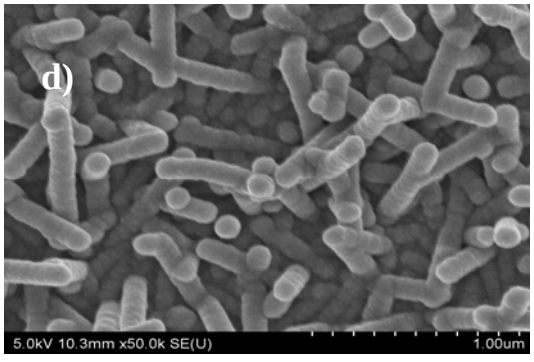


Fig.4: SEM images of a virus-coated gold surface immersed in the Palladium solution for an a) overnight, b)2 hours, c)5hours, and d)8hours.

On the above images, we were interested on the number of the particle per unit area. The viruses on the surfaces appear to have different size because the images were taken under different magnification. A particle count was done per μm² on the images of the different species, and the graphs below were constructed in an MS.Excel environment. The error bars represents the broken TMV rods and the particles that do not quite resemble the TMV.

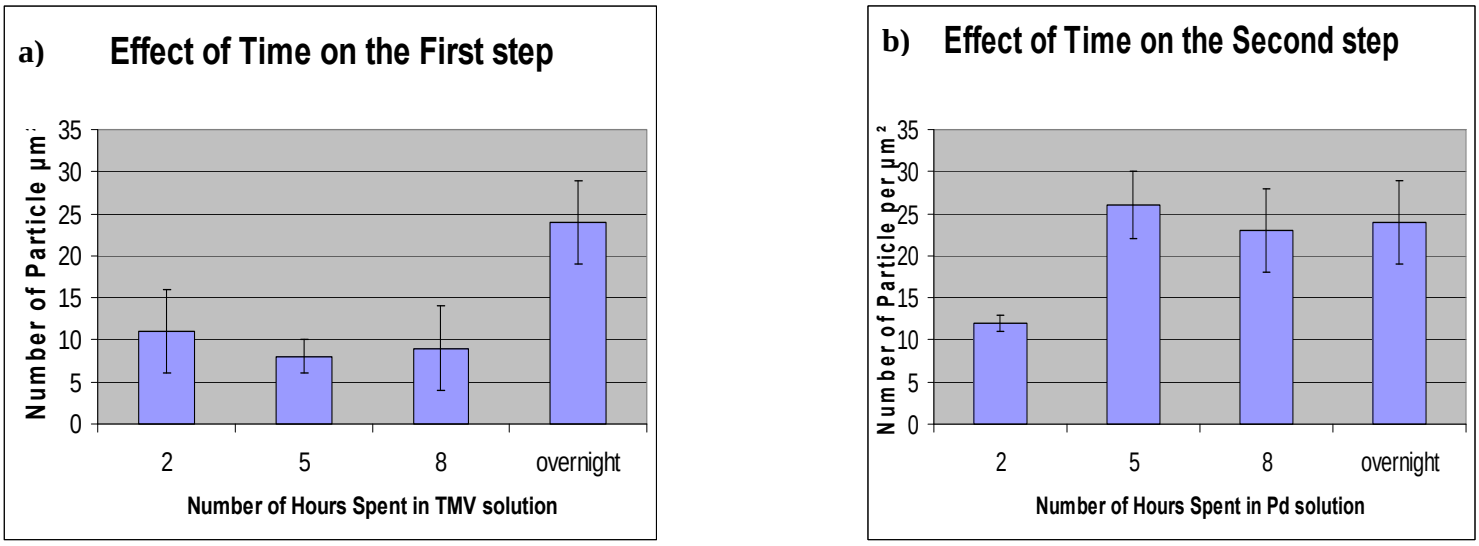


Fig5: Effect of time on a) 1st step b)2nd step

In fig.5a the number of TMV particles counted on gold surfaces that spent 2 hours 5hours, and 8hours in a TMV solution are much less than the particles counted on the surface that had spent an overnight. This means that the TMV need more than just 8 hours to bind onto the gold surface.

In fig.5b, the number of TMV particles counted on the TMV coated gold chips that spent 5 hours, 8hours and overnight in a palladium solution are comparable; whereas the number of particles on the chip that spent only 2 hours is much less. It means that

TMVs are activated after 2 hours and sometimes before or at exactly after 5 hours in a palladium solution. Therefore the chip does not need to be incubated for more than 5 hours to have most of its TMVs activated.

Conclusion

The first step has not been optimized. The results obtained so far show that the gold chip still needs to spend an overnight in the TMV solution. However, the step 2 results show that approximately the same number of virus, as well as the same coating is obtained if the second step is reduced to 5 hours, instead of an overnight.

Acknowledgments

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References

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