DESIGN AND SIMULATION STUDY OF COATED MICRONEEDLE- A MEMS APPLICATION FOR DRUG DELIVERY

Shilpa Nagod
Department of Electronics
Akkamahadevi Women's University, Vijayapura, Karnataka, India
Email- shilpa.nagod@gmail.com

Dr. S. V Halse
Vice-Chancellor
Davangere University, Davangere, Karnataka, India
Email- drsvhalse@rediffmail.com

Abstract- Drug administration through the transdermal route is a developing field which is an alternative to oral and parenteral routes of therapy. Various microneedles based approaches have been developed. MEMS based coated microneedles are a minimally invasive method to deliver drugs and vaccines through the skin which has been a very promising and area of interest in past decade. In this paper we discuss about different coating techniques, design a patch of coated microneedle, determine the pressure at the tip of microneedles through the simulation and importantly, evaluate whether the coating gets peeled during the course of drug administration.

Keywords – MEMS, Microneedles, Coating, Drug delivery

I. INTRODUCTION

Micro-Electro-Mechanical System (MEMS) is the integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate though micro- fabrication technology [1]. MEMS are gaining a lot of attention in the field of biomedicine due to their extensive use in diagnosing and treatment of deadly diseases including cancer. MEMS based microcantilevers are being used as sensors to diagnose the diseases and MEMS based microneedles, micropumps are used in drug delivery. MEMS based stents are useful for treating occluded arteries.

Microneedles are becoming more important because they are pain free and are accurate in the controlled flow of drug delivery. They also provide comfort for the people who suffer "Needle Phobia". Due to their smaller cross sections, they are minimally invasive. The microneedle insertion depth can be well controlled by using appropriate lengths [2]. Microneedle technology is a promising ones in the field of healthcare since it is very precise in injecting by penetrating the stratum corneum but not in penetrating deep enough into the dermis to cause noticeable pain, or are too small to significantly stimulate nerve endings, they are expected to provide almost painless drug delivery [3]. Microneedles, in particular arrays of such needles, have many potential applications in different areas of medicine and biology, such as vaccinations [4], transportation of DNA [5], diabetes and cancer treatment [6.7].

II. COATED MICRONEEDLES

Coated Microneedles are the microneedles that are generally made up of silicon or polysilicon and then they are coated with the desired drugs with appropriate thickness in accordance with the required dosage. They are well utilized in the delivery of potent drugs. The vaccines that are coated onto the microneedle come in contact with Langerhans cells of the skin where they interact with each other [8,9]. When the molecular weight of the molecules in vaccine is high enough, they get delivered rapidly through self-implementation [10]. The shelf-life of coated microneedles is proven to be really good. For example, 98% integrity of desmopressin coated onto microneedle was

maintained after 6 months of storage under nitrogen at ambient conditions [11]. There are also additional benefits of using coated Microneedles such as protection against moisture, high volumes of drug loading[10].The drawback of these coated microneedles are that the quantity of the drug to be administered using this method is limited to the amount of the drug that can be coated onto the tips and shafts of microneedles. Coated MNs retain their mechanical strength; however, their tip sharpness is reduced and this impacts skin penetration ability.

III.DESIGN AND MODELING OF A MICRONEEDLE

In this work, we have designed a patch of microneedle array and simulated it to analyze whether the coating of microneedle is peeled off in the very action of piercing and drug administration. The geometry of the model is determined through the average dimensions of earlier research work in literature. The design parameters are mentioned in the table below:

Parameters	**Value**
Length of Microneedle	650um
Diameter of microneedle tip	80um
Coating Thickness	5um
Young's Modulus of Microneedle material	170Gpa
Poisson's ratio	0.28
Density	2329kg/m3

Table 1: Design Parameters

Geometry

In this work in order to have thorough understanding and ease of simulation a patch of four microneedles is designed. The geometry of the model designed with the above mentioned parameters is as shown in the figure below

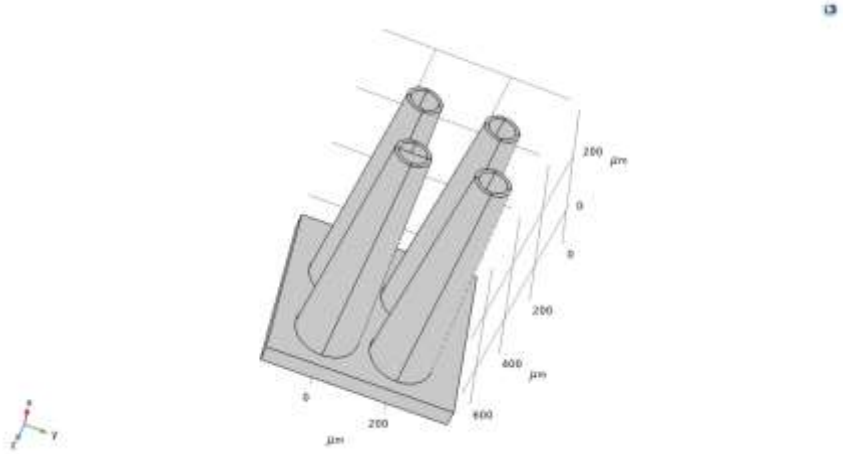

Fig. (1) Geometry of coated microneedles

These microneedles are made up of silicon and the coating material is added as user defined material with the properties like of doxorubicin which is the medicine used for cancer treatment since doxorubicin is not directly available in the tool materials library. The density of Doxorubucin is 1.6+/-0.1g/cm3 [12]. The binding strength of drug depends on the glue which is used. Through the literature the young's modulus of glue is 50-60Mpa [13]. Thus we need to prove that the Von Mises Stress along the binding boundary must be less that 50-60Mpa so that the coated drug is not peeled. A stationary Solid Mechanics physics is used in this simulation study. A uniform boundary load of 0.02158N is applied in each of the direction. The base of the microneedle and the interface of the coating and microneedle would be fixed.

Mesh

The physics-controlled mesh with extremely fine element sized meshing is done. Complete mesh consists of 222627 domain elements, 64891 boundary elements, and 3467 edge elements.

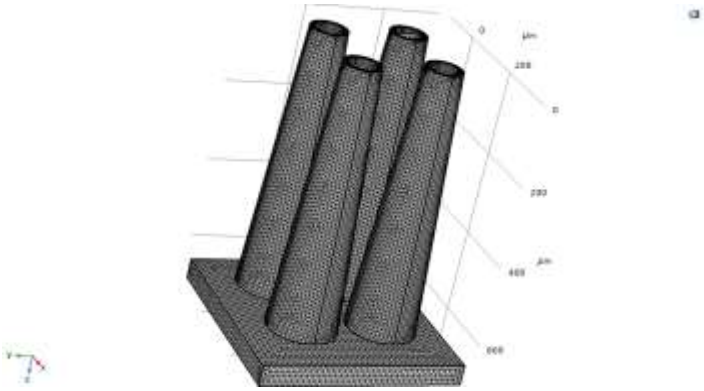

Fig. (2) Meshing of Microneedle

Results

The resultant Von mises stress at the interface of coating and microneedle is 9.61Mpa as per the simulations. This is far lesser than that of 50-6-Mpa. Thus it can be inferred that the coating doesn't get peeled.

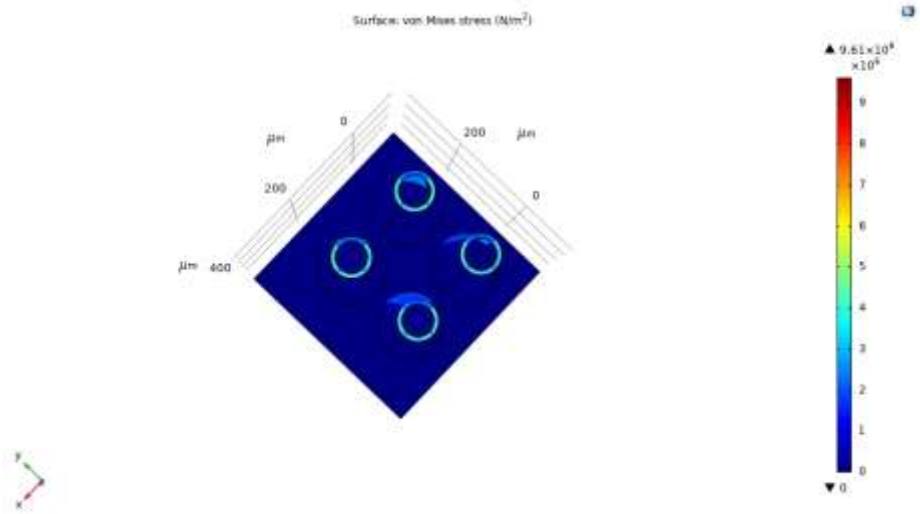

Fig. (3) Stress at Microneedle-Coating Interface

From the graphical representation it can also be deduced that the microneedles have pressure enough to pierce through the skin so that the drug administration can take place successfully.

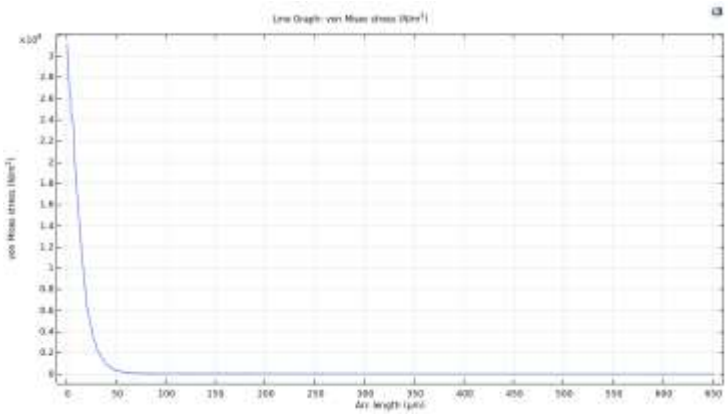

Fig. (4) Graph depicting the piercing pressure

IV.CONCLUSION

A brief review of Microneedles was done, a coated microneedle made up of silicon was modeled and simulated using Comsol Multiphyiscs. It is deduced from the simulation result that the pressure at the microneedle-coating interface is much lesser (9.6Mpa) in comparison to that of glue (50-60Mpa), hence the drug coating will not be peeled or chopped away during the insertion of microneedle.

REFERENCES

[1] http://www.mems-exchange.org/MEMS/what-is.html

[2] Chandrasekaran S, Brazzle JD, Frazier AB (2003) Surface micromachined metallic microneedles. J Microelectromech Syst 12(3): 281–288. doi:10.1109/JMEMS.2003.809951

[3] Kaushik S, Hord AH, DDand Denson et al (2001) Lack of pain associated with microfabricated microneedles. Anesth Analg 92:502–504. doi:10.1097/00000539-200102000-00041

[4] Mikszta JA, Alarcon JB, Brittingham JM et al (2002) Improved genetic immunization via micromechanical disruption of skinbarrier function and targeted epidermal delivery. Nat Med 8:415–419. doi:10.1038/nm0402-415

[5] Chabri F, Bouris K, Jones T et al (2004) Microfabricated silicon microneedles for nonviral cutaneous gene delivery. Br J Dermatol 150:869–877. doi:10.1111/j.1365-2133.2004.05921.x

[6] Drum D (1996) Making the chemotherapy decision. Lowell House, Los Angeles

[7] Smart WH, Subramanian K (2000) The use of silicon microfabrication technology in painless blood glucose monitoring. Diabetes Technol Ther 2(4):549–559. doi:10.1089/15209150050501961

[8] Bal, S.M.; Ding, Z.; van Riet, E.; Jiskoot, W.; Bouwstra, J.A. Advances in transcutaneous vaccine delivery: Do all ways lead to Rome? J. Control. Release 2010, 148, 266–282.

[9] Bubiuk, S.; Baca-Estrada, M.; Babiuk, L.; Ewen, C.; Foldvari, M. Cutaneous vaccination: The skin as an immunologically active tissue and the challenge of antigen delivery. J. Control. Release 2000, 67, 415.

[10] Gill, H.S.; Prausnitz, M.R. Coated microneedles for transdermal delivery. J. Control. Release 2007, 117, 227–237.

[11] Cormier, M.; Johnson, B.; Ameri, M.; Nyam, K.; Libiran, L.; Zhang, D.; Daddona, P. Transdermal delivery of desmopressin using a coated microneedle array patch system. J. Control. Release 2004, 97, 503–511

[12] www.chemspider.com/Chemical-Structure.29400.html

[13] Yang, Y C, and E Chang. “Influence of Residual Stress on Bonding Strength and Fracture of Plasma-sprayed Hydroxyapatite Coatings on Ti-6Al-4V Substrate.” Biomaterials 22.13 (2001): 1827–36.