Utilization of Soft Materials as Flexible Sensors for Detection of Skin Stretching and Surface Strain

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***Abstract*—This technical document is a comprehensive overview of current uses of soft materials and their compatibility with conductive materials to facilitate the creation of a device that can detect signs of intravenous (IV) infiltration, specifically increased skin stretch and surface strain which cause measurable fluctuations in the resistance of conductive materials. Also discussed are the specific purpose, mold design processes, soft and conductive materials used, methods of data collection as well as sensing resolution for each system. The final infiltration detection device design concluded upon in the results is derived from past advances discussed throughout this document. The device will utilize a soft elastomer with two microchannels filled with the liquid metal eutectic Gallium-Indium to detect surface strain on the catheter area.**

I. Introduction

The focus of this document is determing the most effective method for utilizing soft materials in conjunction with other components in order to better detect infiltration through the symptoms of skin stretch and surface strain. Novel methods for advancing the ability to detect IV infiltration are able to be concluded from previous studies discussed throughout this document [1-15]. IV infiltration is the condition where fluid being administered secretes from the target vein into surrounding tissue where it can cause serious damage if not noticed quickly. The detection of infiltration is especially a concern for infants due to their inability to communicate pain and other symptoms. The development of soft materials in conjunction with other components for a wide variety of medical applications has greatly increased in recent years. These technologies range from artificial skin sensors with multi-modal sensing [1], to wearable devices to detect motion [3], and finally measuring biomedical signals such as electrocardiograms (ECGs) and respiration [4]. Most applications to be discussed have similar processes for designing the silicone mold and the embedded micro-channels, with variances in the designs that are specific to each application. There are three major implementations for collecting data from micro-channels. The first method discussed involves filling a set of micro-channels with a liquid-metal and subsequently filling a separate set of parallel micro-channels with a Room Temperature Ionic Liquid (RTIL) [3]. The specific liquid metal used is eutectic Gallium Indium (EGaIn) and the RTIL used is 1-ethyl-3-methylimidazolium ethyl sulfate. The next method solely uses EGaIn to act as a flexible conductor with the capability of detecting stress within the micro-channels [1]. The final method involves copper electrodes capable of detecting stress [2]. This capability is dependent upon measuring changes in electrical properties of the metal. Different soft materials and their respective properties are discussed along with the processes used to mold them into the desired shapes. The properties of each different medium discussed such as EGaIn, RTILs, and copper are further analyzed in other applications including stretchable sensing systems [5], hyperelastic strain sensing [9], formation of stable structures within elastomers [11], and implementation in ECG electrodes [13].

Fig. 1. Implementation of artificial skin containing micro-channels to model hand gestures [3].

II. Purpose

The first application to be discussed uses RTILs and EGaIn in order to detect hand gestures as shown in Figure 1 [3]. An artificial skin that resembles a glove is placed over the hand and fastened with velcro ties. This skin contains a parallel set of micro-channels that are able to monitor and transmit changes in stresses such as pressure and stretching. The application of this prototype was developed primarily for new human-computer interaction functionality at an effectively low cost of production. The second application involves a three-dimension sensing system as shown in Figure 2 on the next page [1]. This system was developed for the same purpose of advancing the field of human-computer interaction such as artificial skins for humanoids, robotic prosthetics, and wearable robots. The advantage of this device is that its multi-dimensionality provides a novel method for stress detection without requiring additional sensors to be placed on the area of interest. The next method of detection uses copper electrodes that are placed within the silicone mold to measure the dielectric and strain properties of the test area. Reference [2] provides a method of detection using copper electrodes that are placed within the silicone mold to measure the dielectric and strain properties of the test area. The sensor is shown in Figure 3. This setup is much more complicated than previously discussed methods in that it requires equipment that can deposit the copper through electron beam evaporation; however, it is extremely thin and provides for wireless detection whereas the previous methods do not possess this capability. Reference [4] presents an application of soft, textile materials to record different physiological signals. This design consolidates all of its components within a conductive and piezoresistive material such as fibers and yarns. The study reveals that the textile material is as accurate as silicone, providing an inexpensive alternative to its counterpart. Soft sensors have also been developed by adapting a barometric sensor to be used as a highly sensitive pressure sensor [5]. This method was a general application intended to be used in the sports and medical fields. The idea of creating sensors solely out of soft materials was proposed in the conclusion. Soft sensors would no longer contain metals and other solid materials in order to provide a more comfortable experience for the subject. This would prove extremely useful in not only the areas of sports and medical applications but many others as well such as human-computer interaction and motion sensing. Another method presented that differs from previous methods discussed is shown in Figure 4. This design uses a liquid metal capacitor placed between two liquid metal-filled microchannels for strain sensing similar to the designs discussed earlier [7]. The objective of this device is to more accurately sense strains on a surface within two millimeters. The final implementation to be discussed focuses on the liquid metal, EGaIn, to act a a flexible circuit for non-invasively measuring ECG signals [8].

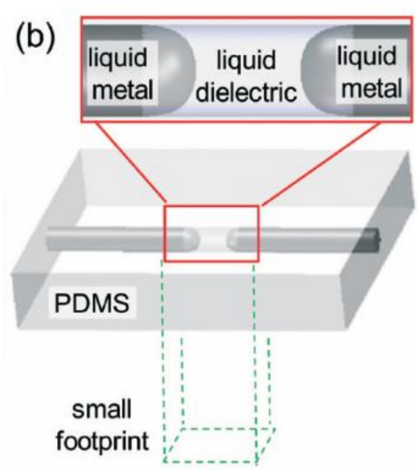


Fig. 4. Model displaying a single-channel, two liquid material design for detecting strain [7].

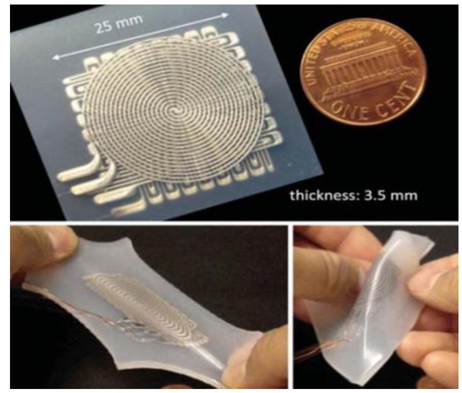


Fig. 2. Implementation of artificial skin for three-dimensional sensing [1].

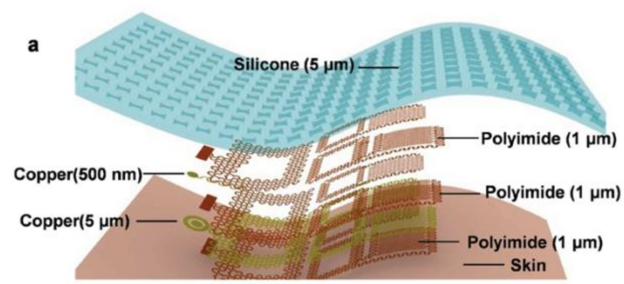


Fig. 3. Detailed construction of silicone mold containing copper for stress detection [2].

III. Design

A. Soft Materials and Molding Processes

The soft materials used in previous experiments above consist primary of silicone. This material is easily moldable by using 3-D printed plastic molds to form its shape. Due to its amorphous state, it can readily form around components such as strain gauges. The only problem that arises is that this material has an extremely high melting point in order to become amorphous, around 300 degrees celsius. However, this problem can also be a positive for use in extreme environments like firefighter vital detection while on the field. For the purpose of medical applications, the high temperature needed to melt silicone prevents it from being able to mold around objects without melting the object. Experimenters referenced in this document maneuver around this obstacle by forming the molds separately in 3-D printed plastic and then subsequently placing them around the object to be encased. Asforementioned, most materials used in the discussed experiments consist of silicone but with the exception of the material presented in Reference [6]. This reference provides an in-depth description of the molding process for creating plastic masters, also known as PMs. PMs are advantageous to silicone based materials due to their ability

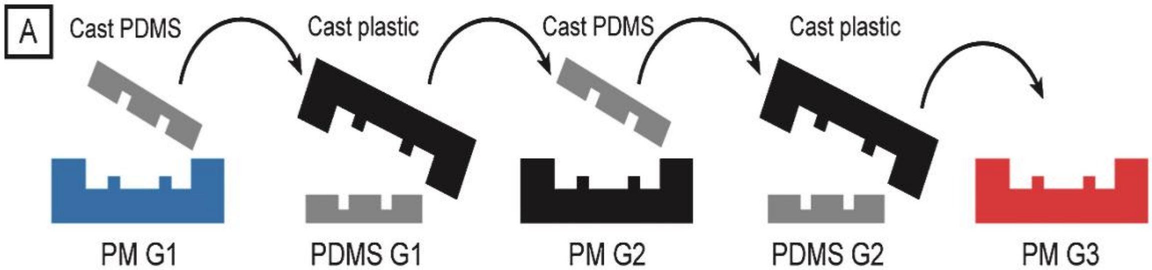
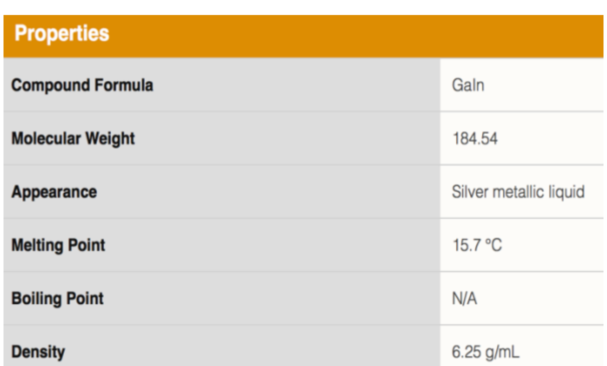


Fig. 5. Mold process for PM material yielding a three generations [6].

to be easily replicated outside of a cleanroom as well as their cost-effectiveness. The process used in this experiment is displayed in Figure 5 above. In order to get an accurate mold, the process for creating the final PM is executed three times until the third generation mold is nearly perfect.

B. Conductive Materials

Conductive materials used in conjunction with soft materials mentioned above include eutectic Gallium-Indium (EGaIn), Room Temperature Ionic Liquids (RTILs), and copper metal. The properties of EGaIn material are displayed in Figure 6. EGaIn is chosen in experiments due to its "skin" that will allow for the material to keep its shape until its surface tension is broken. Experiments such as that in Reference [3], use the EGaIn to fill microchannels and act as flexible wires that transmit data from the parallel microchannels filled with RTIL. In this method, the RTILs are able to detect variances in strain through their electrical conductivity as soft joint strain sensors. Other experiments such as that in Reference [1], use EGaIn in microchannels to act as a flexible strain sensor. In addition, the microchannels are layered on top of each other, creating a three dimensional soft artificial skin-like material with a thickness of 3.5 millimeters. The final conductive material used is copper metal as described in Reference [2]. The copper is enclosed in a silicone layer and an additional layer of polyimide to prevent confounds caused by humidity.



Properties	
Compound Formula	GaIn
Molecular Weight	184.54
Appearance	Silver metallic liquid
Melting Point	15.7 °C
Boiling Point	N/A
Density	6.25 g/mL

Fig. 6. Properties of eutectic Gallium-Indium [REMOVE]

C. Soft and Conductive Material Interaction

Microchannels are formed within soft materials using molds as previously described. These microchannels are then filled with the eutectic through injection. Injection alone does not necessarily break the "skin" of the eutectic so an additional syringe is used on the opposing sides of the microchannels to extract air. By extracting air, the pressure within the microchannels increase and the eutectic is able to readily flow. Once the eutectic is in place, as in Reference [1], it is able to have electricity passed through it and subsequently its resistivity can be measured. An increase in resistance signifies an increase in strain. Depending upon the design, the eutectic can communicate this increase in resistance directly to the measurement tool. Reference [3] utilizes the RTIL, 1-ethyl-3-methylimidazolium ethyl sulfate, in lieu of the eutectic. The RTIL then communicates its mechanical strain to the eutectic that acts as a flexible wire as mentioned before. In this specific experiment, hydro-chloric acid is injected into the microchannels prior to the injection of the eutectic. This process relinquishes the need to use another syringe to increase pressure in the system. The pre-injected acid breaks down the skin of the eutectic allowing it to readily flow through the microchannels. The last conductive material, copper metal, is used to measure changes in strain by assessing its variances in frequency as opposed to measuring changes in electrical resistance through liquids [7]. The copper metal acts as an electrode whose frequency will vary with changes in epidermal properties. These frequencies are able to be mapped and associated with changes in strain. By measuring the resonant frequencies created by these capacitors, changes in strain and stretch of the skin are able to be wirelessly detected. This method allows for non-invasive and almost unnoticeable use on subjects. Finally, strain gauges are used in place of previously mentioned conductive materials. Strain gauges are fairly expensive but relative to using the eutectic, they are cost-effective. These components are small which allows for multiple contact points. However, strain gauges can prove to be difficult to place within silicone and other soft material molds as the pressure created inside the mold or the thickness of the mold can negatively affect results attained by the strain gauge.

IV. CONCLUSION

The field of soft materials and its interaction with other materials and components such as eutectic Gallium-Indium, Room Temperature Ionic Liquids, and copper metals has made many advances in recent years. These materials used in conjunction with the objective of sensing strain and stretch of the skin display accuracy in detecting these effects. With this level of accuracy, a threshold for the amount of strain or stress the area of skin at the catheter site can be mapped. With this threshold, intravenous infiltration can be detected almost immediately. Most importantly, it can be detected before it can cause any significant damage to the patient. These advances are excellent starting points for deciding on a non-invasive method to detect intravenous infiltration as well as alert staff once the condition has been detected.

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