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Wrinkled nitrile rubber films for stretchable and ultra-sensitive respiration sensors

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ABSTRACT

Respiration pattern (including both breath rate and intensity) is critical vital symptoms of many disorders such as sleep apnea, asthma, chronic obstructive pulmonary disease, and anemia. Breath sensors that can distinguish abnormalities in breath patterns can ascertain the basic human body conditions during sleep, exercise, sports and surgery play a significant role in healthcare system and have attracted more and more attentions. However, the existing breath sensors are limited in the sensitivity and not compatible with the practical applications during movements. Here we present a simple approach employing the wrinkled nitrile rubber films to detect the human respiration, both breath rate and intensity The three-dimensional wrinkled structure of nitrile rubber films could significantly increase the capability to distinguish different intensities of respiration, with an average intensity ratio of 16 times for strong breath over weak breath signal These sensors also show fast response (up to 2 Hz) high sensitivity, and can be stretched by 100% with stable breath sensing property. Our respiration sensors are favorable to the urgent healthcare monitoring applications in the near future.

1. Introduction

The aging population, prevalence of chronic diseases, and outbreaks of infectious diseases are some of the major challenges in our present-day society [1–8]. To address these unmet healthcare needs, especially for the early detection and precise treatment of major diseases, health informatics, which deals with the acquisition, transmission, processing, storage, retrieval, and use of health information, has emerged as an active area of interdisciplinary research [1–8]. In particular, acquisition of health-related information by unobtrusive sensing and wearable technologies is considered as a cornerstone in health informatics [1–8]. For human health monitoring, abnormalities in the breath patterns (including rates and intensities) can ascertain some basic conditions of the human body, such as sleep, exercise, anaerobic threshold during athletes, and etc. [9–17]. Abnormalities in breath patterns can reflect some specific illnesses, such as ovarian carcinoma, chronic obstructive pulmonary disease, flu, pneumonia, diagnosing sleep apnea, asthma, lung cancer, and etc. [9–17]. Therefore, respiration sensors play an essential and ubiquitous role in healthcare systems [1–3,7–10].

To detect breathing rate precisely, various methods have been studied, including temperature sensors, pressure sensors, strain sensors, acoustic sensors and optical sensors [1–3,7–10]. Especially breath sensors that can be weaved or integrated into clothing, accessories, and the living environment, such that health information can be acquired seamlessly and pervasively in daily living, play a significant role in healthcare system and attracts more and more attention [1–3,7–10]. Until very recently, two groups have reported effective, simple, inexpensive sensors for direct monitoring respiration that uses the water vapor from respiration for breathing rate sensing [9,10]. Whitesides group reported a breath sensor capable of measuring the rate of respiration of a person by detecting the difference in moisture adsorbed on paper from inhaled and exhaled air [9]. Yoon et al. reported another breath sensor relying on a temporarily condensed water layer that is instantly formed on the surface of an oxidized substrate from exhaled breath and that quickly disappears owing to evaporation [10]. These new findings indicated that insulate films can be used as highly functional sensing materials. However, the sensors based on paper or oxidized substrate are not stretchable, and the capability to distinguish different intensities of respiration is limited. So, although diverse approaches have been attempted, implementing wearable,

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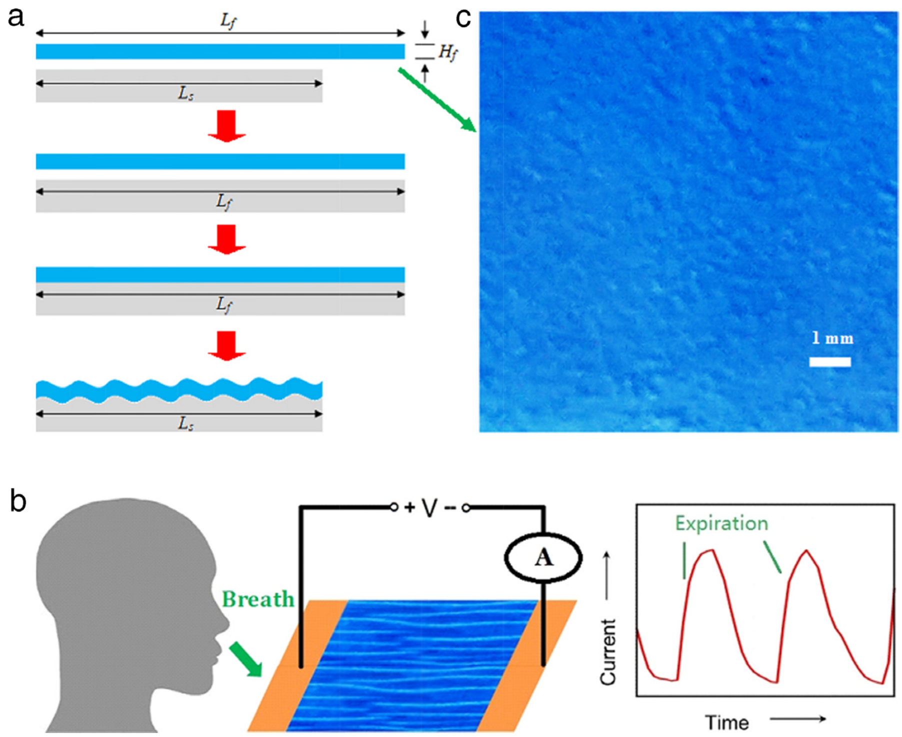

Fig. 1. (a) Schematic illustration of macroscopic deformation of nitrile rubber film on a uniaxially pre-stretched substrate. (b) The schematic diagram of respiration sensors based on wrinkled nitrile rubber film. (c) Optic image of flat nitrile rubber film.

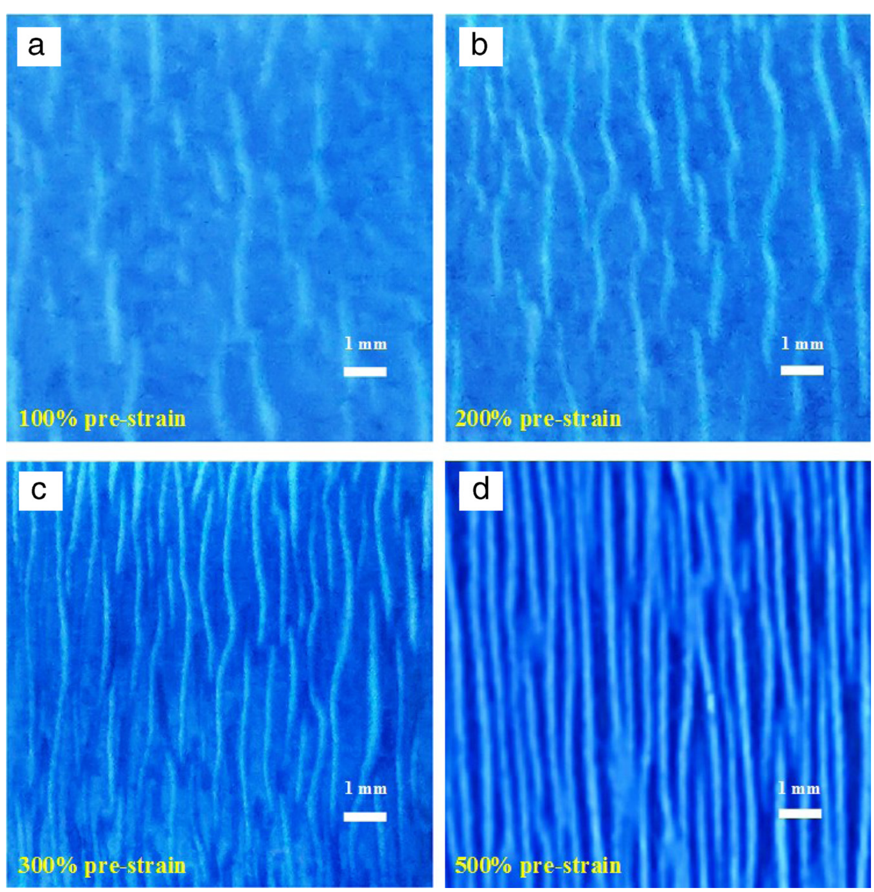

Fig. 2. (a) Optic image of pattern of 3D structure formed by 100% pre-strain. (b) Optic image of pattern of 3D structure formed by 200% pre-strain. (c) Optic image of pattern of 3D structure formed by 300% pre-strain. (d) Optic image of pattern of 3D structure formed by 500% pre-strain.

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