OPTICAL NITRITE SENSOR AND URINE-ACTIVATED ELECTROCHEMICAL POWER SOURCE ON PAPER THROUGH LASER-ASSISTED PATTERNING AND LAMINATION

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ABSTRACT

This paper reports a low-cost solution to the early detection of urinary nitrite, a common surrogate for urinary tract infection (UTI). We report on a simple method to fabricate a flexible optical [1] nitrite sensor and its urine-activated electrochemical source [2] on a hydrophobic (wax) paper through laser-assisted patterning and lamination. Such device can be embedded onto a diaper and deliver semi-quantitative information in a point-of-care fashion.

KEYWORDS: Nitrite sensing, Urinary tract infection, Electrochemical cells, Paper, Laser patterning

INTRODUCTION

Although there are commercially available test strips for colorimetric urinary nitrite detection [3][4], such devices are not easily adaptable for UTI detection in infants and elderly adults suffering from dementia (the two main population using diaper). In particular the latter group suffer frequent episodes of UTI and are unable to communicate their symptoms to caregivers. Our device combines the colorimetric reagent utilized in most conventional dipsticks, a LED/photodiode detection unit and a zinc-copper battery, fabricated on a hydrophobic paper. This flexible device could be embedded onto a diaper along with a wireless transmitter and screen for UTI.

THEORY

The schematic of the device is shown in Figure 1. It is comprised of a zinc-copper electrochemical battery, a green LED, and a photodiode, all integrated onto a wax paper (Figure 1a). Prior to use, the device is folded along the dash line (Figure 1a) such that the LED and the photodiode overlap and align. Prior to folding, a test strip containing the "Griess reagent" (e.g. p-arsanilic acid and N-ethylenediamine dihydrochloride (N.E.D.)) is intercalated in between the LED and photodiode (Figure 2f).

Once the device is wetted by urine, the battery is activated (redox reactions are enabled through moist salt bridge), turning on the LED/photodiode detection unit. Simultaneously, the test strip samples the urine for the presence of nitrite which reacts with p-arsanilic acid to form a diazonium compound, in turn coupling with N.E.D. and changing the white strip to pink (the complementary color to green, thus retarding the transmission of green light). The intensity of the transmitted light through the test strip and hence voltage drop across the resistor in series with the photodiode is a function of nitrite concentration.

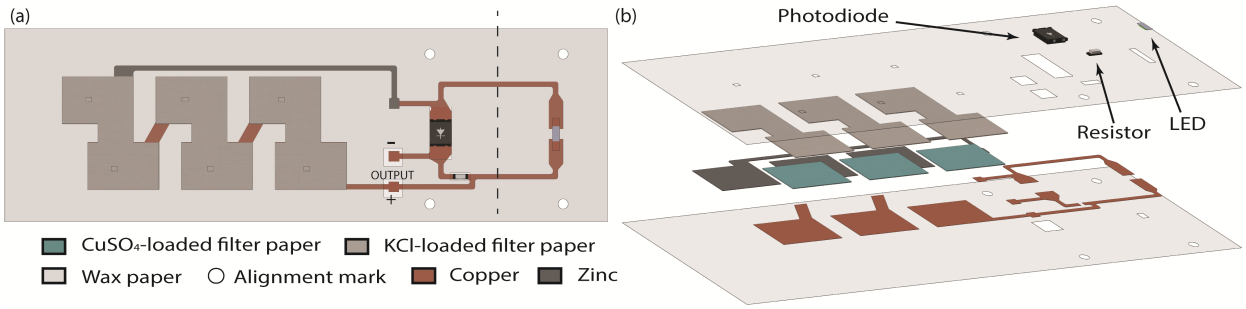

Figure 1: (a) Schematic of the sensor (top view) showing a three cell electrochemical source and colorimetric optical nitrite sensor on a flexible substrate. (b) Exploded view of the device.

EXPERIMENTAL

Fabrication process starts with laser machining (fiber laser 1.06 μm) copper and zinc (50 and 100μm thick, respectively) tapes with an adhesive backing to create the metal electrodes for the battery module and traces for the sensor/circuit (Figure 2a). Then, two sheets of wax paper are patterned (Figure 2b) using a CO_2 laser. The first one is used for the top cover and incorporates access holes for both battery activation and assembly of the photodiode (430-610 nm) and LED (566 nm) along with marks for aligning the photodiode/LED detection unit. The second paper acts as the bottom support and incorporates access window and alignment marks. Two separate filter papers, one impregnated with potassium chloride (salt bridge) and the other with copper sulfate (the electrolyte) are sandwiched and laminated along with the patterned metal tapes in between the wax papers (Figure 2c, d). Finally the photodiode, green LED, and a surface mount resistor are soldered onto the substrate (Figure 2e) so that the folded device is ready to use with a test strip inserted (Figure 2f). The test strip is made of filter paper and transparent tape bonded together between which there exists an even distribution of p-arsanilic acid and N.E.D. mixed at 10:1 weight ratio. Figure 3 shows photographs of an unfolded and folded fabricated device with a 3 cell battery in isolation and being embedded into a commercial diaper.

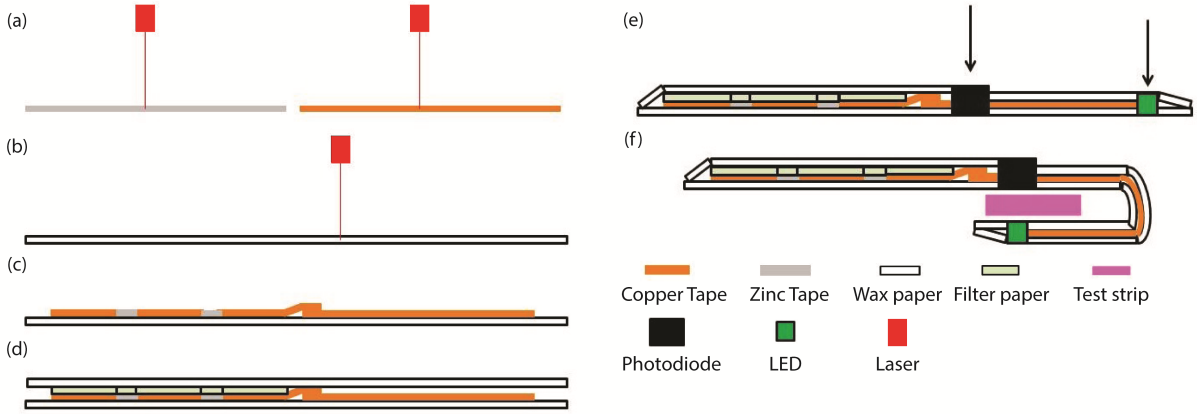

Figure 2: Fabrication process of the integrated electrochemical nitrite sensor for UTI detection. (a) Defining the electrochemical electrodes and the circuit traces on zinc and copper tapes using fiber laser. (b) Defining the opening on wax papers (substrate and top cover) using CO2 laser. (c) Bonding the metal tapes onto the substrate. (d) Alignment and laminating-assembly of the substrate, filter papers (electrolyte and salt bridge) and the top cover. (e) Soldering a photodiode and LED. (f) Folding the device and inserting a test strip in between the photodiode and LED.

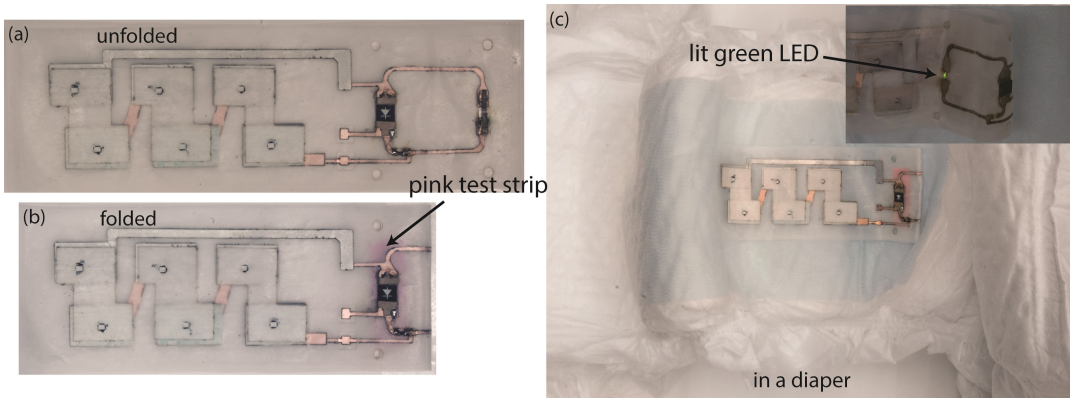

Figure 3: Final fabricated device, left panel showing an (a) unfolded and (b) folded substrate with LED and photo-diode, (c)right illustrating the sensor embedded onto a diaper and inset demonstrating the green LED lit on upon the wetting of the electrochemical battery (the paper substrate is flipped over to let the LED face up).

RESULTS AND DISCUSSION

Upon contact with urine, the battery is activated (2.8V, ~100 seconds activation time) powering the LED/photodiode detection unit (Figure 3c inset). Simultaneously, the test strip changes color from white to pink in the presence of nitrite in the urine, resulting in the absorption of the transmitted green light. Figure 4 illustrates the characteristic curve of the nitrite sensor exposed to 0.01, 0.001, 0.0001 g/L nitrite solutions (in healthy people the nitrite concentration in urine is zero, hence presence of any nitrite is an indication of UTI).

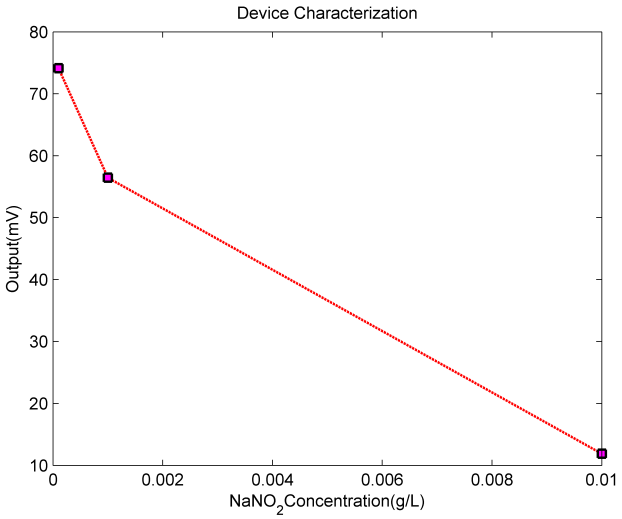

Figure 4: Device characterization curve showing output voltage at three different nitrite concentrations.

CONCLUSIONS

We demonstrated a simple and easy way to fabricate a flexible nitrite sensing platform along with its electrochemical power source on a single wax paper through laser machining-patterning and lamination-assisted packaging. The device is potentially a cheap alternative solution to the conventional dipstick urinalysis for the timely screening and diagnosis of UTI.

ACKNOWLEDGEMENTS

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