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Research paper

The effect of the gas diffusion layer on the performance of fuel cell catalyst layers in ethanol sensors

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ABSTRACT

The influence of the gas diffusion layer (GDL) on sensing performance of two commercially available fuel cell catalysts and membranes were investigated in an ethanol sensor. The catalyst used was either platinum black (Pt) or 20% platinum on carbon (Pt/C). These catalysts were coated onto a carbon paper, carbon paper with a microporous layer and carbon cloth GDL. Nafion and porous polyvinyl chloride (PVC) containing sulfuric acid were used as membranes. A fourth sample set with no GDL present was also tested. It was found the GDL's effect on performance depended on the membrane electrode assembly (MEA) employed. For a Pt-Nafion MEA, the carbon cloth GDL showed the best performance compared to the other two GDLs and no GDL. The removal of the GDL significantly impacts the structural integrity of the catalyst layer, effecting performance. MEAs prepared with a carbon paper GDL were prone to localized flooding at higher humidity's. Pt/C-Nafion MEAs showed similar performance, regardless of GDL. Removal of the GDL with a Pt/C catalyst greatly affected the structural integrity of the MEA, decreasing performance. PVC membranes are more flexible in the choice of GDL and catalyst layer. Overall, the carbon paper-MPL-Pt/C-PVC showed the best performance due to having the greatest stability in performance at the two humidities tested.

1. Introduction

Breath alcohol sensors (BrAS) are one of the most important tools for law enforcement. These devices allow for the quick analysis of a suspected intoxicated individual. They have been used for decades by law enforcement and are currently finding their way into vehicles as interlock systems for convicted individuals. These devices operate by measuring the concentration of ethanol in a breath sample and correlating that to the concentration of alcohol in the blood. There are various methods to measure the alcohol content, with the most accurate being infrared and fuel cell based devices [1]. While the performance of both devices are similar [2,3], the fuel cell system is much more portable, and thus is much easier to use for road side testing. As fuel cell devices operate as both evidentiary and screening devices, it is important that these devices function properly to ensure accurate results.

The fuel cell sensor operates on a very basic principal. A fixed volume of breath is introduced into the anode compartment where ethanol vapor will be oxidized to create protons, electrons, and various by-products, with the acetic acid (Eq. (2)) being the most common reaction product [4,5].

$$C_2H_5OH \rightarrow CH_3COH + 2H^+ + 2e^- \quad (1)$$

$$C_2H_5OH + H_2O \rightarrow CH_3COOH + 4H^+ + 4e^- \quad (2)$$

$$C_2H_5OH + 3H_2O \rightarrow CO_2 + 12H^+ + 12e^- \quad (3)$$

The current produced in this reaction can be measured and used to correlate to how much ethanol was in the breath sample. This then can be correlated to the alcohol concentration in the blood using a well-documented Henry's Law ratio of 2100:1 blood-to-air, respectively [6].

While power-generating fuel cells have evolved over the decades to improve performance, the membrane electrode assemblies (MEAs) found in commercial fuel cell BrASs still use technology from the 1970's. The electrodes are composed of platinum black (Pt) with polytetrafluroethylene (PTFE) binder on a porous polyvinyl chloride (PVC) membrane loaded with sulfuric acid [7]. The platinum loading of this MEA is ca. 14 mg/cm^2, which is significantly higher than what is found in modern power generating fuel cell devices (on the order of 0.5–1 mg/cm^2) [8–10]. Finally, the relative humidity (RH) of the environment in which these devices

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operate in the field varies widely depending on where the device is located in the world. Power generating devices usually operate at near 100% RH using hydrated gases.

Given their similarity, there is great potential to adapt advanced in power generating fuel cells into fuel cell-based BrASs. Recent reports from our group and others have demonstrated the viability of employing fuel cell electrodes with reduced platinum loadings in BrASs. [7,11–14]. These studies have also shown that Nafion membranes, common in power-generating fuel cells, can be successfully employed in BrAS devices.

It is worth noting that many of the recent reports employed MEAs constructed with gas diffusion layers (GDL) [6,7,12,14,20]. The GDL is located between the catalyst layer and the gas inlet, as shown in Fig. 1. The GDL is typically made from a highly porous electrically conductive carbon substrate such as carbon fibre paper (CFP) or carbon cloth. The purpose of the GDL in a power generating MEA is to facilitate gas transport, provide a highly conductive electronic pathway to the current collector, and also aid in water management of the MEA [16–19]. Normally, the GDL has been wet-proofed with PTFE to prevent the accumulation of liquid water within the pores.

While the importance of the GDL in power generating fuel cell performance is well understood, how the GDL's influence on BrAS performance is not. In fact, a GDL is not found in any commercial BrAS MEA device. Thus, it is unclear as to how the presence of a GDL influences the sensing capabilities. For example, the presence of could alter gas transport properties and/or water retention capabilities of the sensor. As such, this work expands on our previous work and seeks to investigate the role of the GDL in ethanol BrAS MEAs. Using our state-of-the-art sensor cell and testing station, various MEAs were fabricated using both Nafion and commercial PVC membranes paired with electrodes prepared from either platinum black and platinum on carbon (Pt/C). Various GDLs were chosen, including the commonly used carbon paper and carbon cloth, as well as test the various MEAs without a GDL. A commercial MEA from Dräger is used in our cell to validate the results as well.

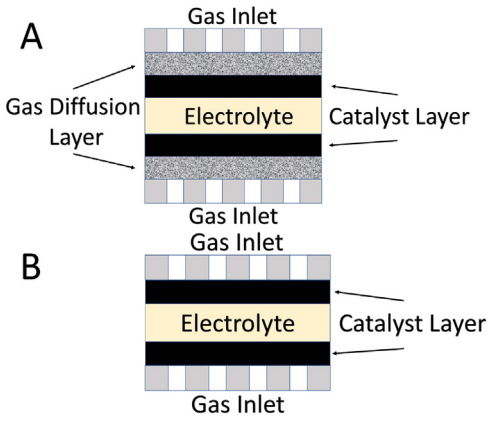

Fig. 1. A.) Schematic of a typical power generating fuel cell membrane electrode assembly (MEA) with a Gas Diffusion Layer (GDL). B.) Schematic of a MEA commonly found in commercial breath alcohol sensor devices. Note that no GDL is used in commercial MEAs.

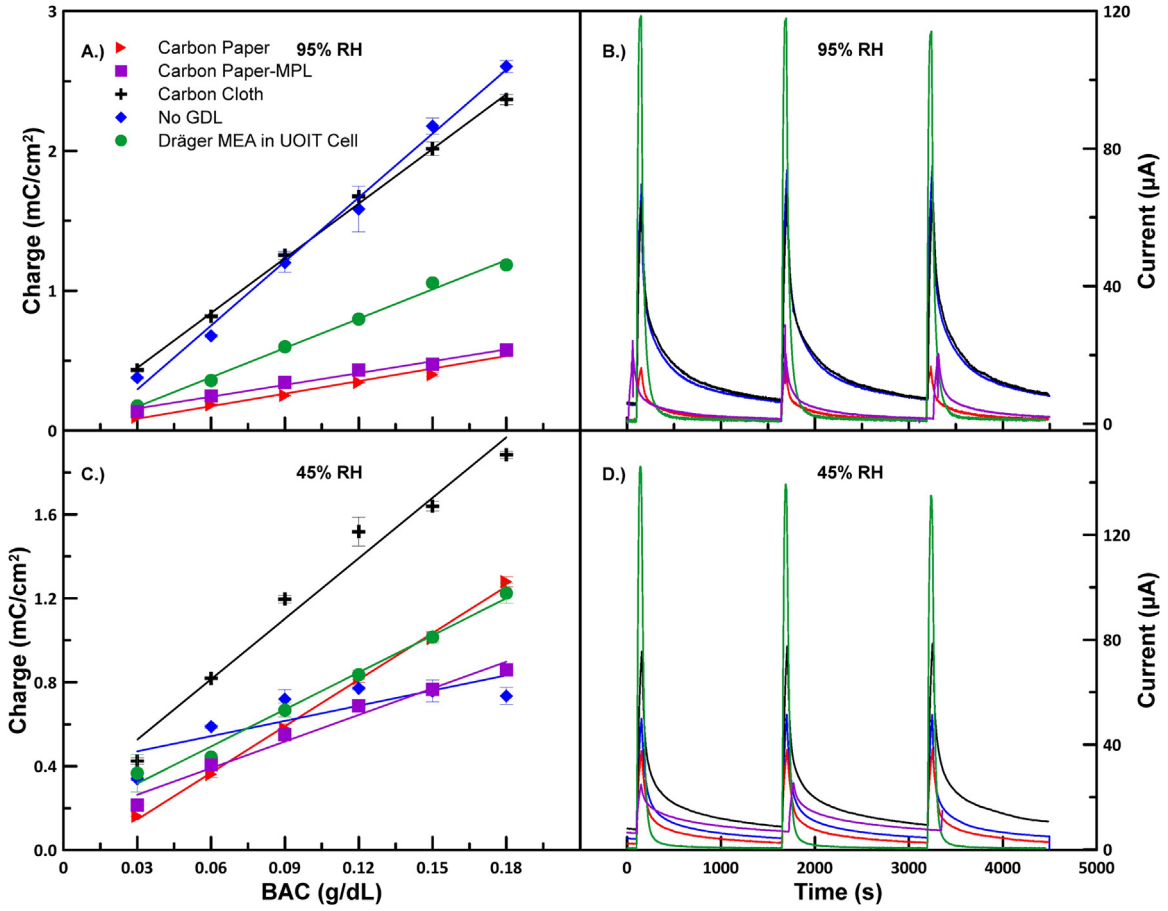

Fig. 2. A.) and C.) Response Plots for a Nafion MEA with JM_{100} on carbon paper (platinum loading: 0.87 mg/cm^2), carbon paper-MPL (platinum loading: 0.93 mg/cm^2), carbon cloth (platinum loading: 0.35 mg/cm^2), and no GDL (platinum loading: 0.35 mg/cm^2) and B.) and D.) transients at 0.09 BAC for mentioned MEAs. Measurements taken at 25 °C.