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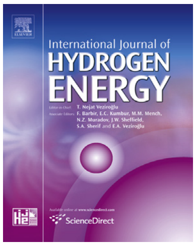

Counter-intuitive reduction of thermal contact resistance with porosity: A case study of polymer electrolyte membrane fuel cells

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ABSTRACT

The present study reveals that the conventional notion that thermal contact resistance increases with porosity does not necessary hold. It is proved through a mechanistic robust model that, under specific circumstances, the porosities of two contacting bodies attain a critical value beyond which the contact resistance counter-intuitively drops. The model focuses on micro porous layers (MPLs) coated on gas diffusion layers (GDLs) of polymer electrolyte membrane fuel cells (PEMFCs) and is validated with the MPL-GDL thermal contact resistance measured over a range of pressure.

The counter-intuitive reduction of the contact resistance with porosity can find important applications in energy conversion systems such as PEMFCs and batteries where contact resistance plays a major role in ohmic loss and heat management. This game-changing finding can lead to improving mass and heat transfer, diffusivity and permeability of porous materials by increasing the porosity without any compromise on contact resistance or ohmic loss. The present cutting-edge research can also open new avenues for fuel cell and any other manufacturers to develop state-of-the-art materials with higher porosities but lower contact resistances, which are currently not available in the market.

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Introduction

Contact or interfacial resistance plays a major role in ohmic loss and electrical and heat management of energy conversion systems such as fuel cells, batteries and capacitors comprised of microstructural porous materials [1–3]. This interfacial resistance, together with the bulk transport properties, is a strong function of porosity [4–6]. A high porous material provides higher heat [7] and mass transfer, diffusivity and permeability but also higher contact resistance and ohmic loss [8,9]. This crucial trade-off dramatically influences heat, electron and ion transfer in fuel cells and batteries. Contact resistance (ohmic loss) reduction and heat transfer, diffusivity and permeability improvement are simultaneously favored in energy conversion devices [10]. However, no reduction of contact resistance with porosity has been to date reported. All attempts have failed to resolve the tradeoff between porosity-based transport properties and contact resistance (or ohmic loss).

The aim of this study is to explore the possibility of contact resistance (or ohmic loss) reduction with porosity through a mechanistic robust model. The focus will be on the interface of two widely-used carbon-based porous materials: a fibrous porous medium called gas diffusion layer substrate and its neighboring micro porous layer (MPL) (see Fig. 1) of polymer electrolyte membrane fuel cells (PEMFCs). The MPL carbon particles clusters and their contact with one fiber are schematically illustrated in Fig. 2. The present model allows the systematic investigation of the effect of GDL and MPL porosities on their contact resistance and provides insights and guidance for the development of new and improved materials for energy conversion systems.

Model development

Geometrical model

A schematic of the contact between spherical carbon particles of an MPL and cylindrical carbon fibers of a GDL is shown in Fig. 3. The random distance between the fibers of the GDL surface [11] and the carbon particles of the MPL surface are exaggeratedly illustrated in Fig. 3. This figure also shows some ellipses as the contact areas between one fiber and several carbon particles. The assumptions of the proposed model include: 1) steady state heat transfer; 2) constant thermophysical properties; 3) cylindrical GDL fibers; 4) spherical MPL carbon particles; 5) elastic deformation; 6) static mechanical contact, i.e., no vibration effects; and 7) short-range surface forces are negligible (Hertz/Surface forces ≈ 10^2 for carbon particle-fiber contacts) [12–14]. The geometrical equations and parameters of the GDLs and MPLs required in the present model are summarized in Table 1. Further details on the

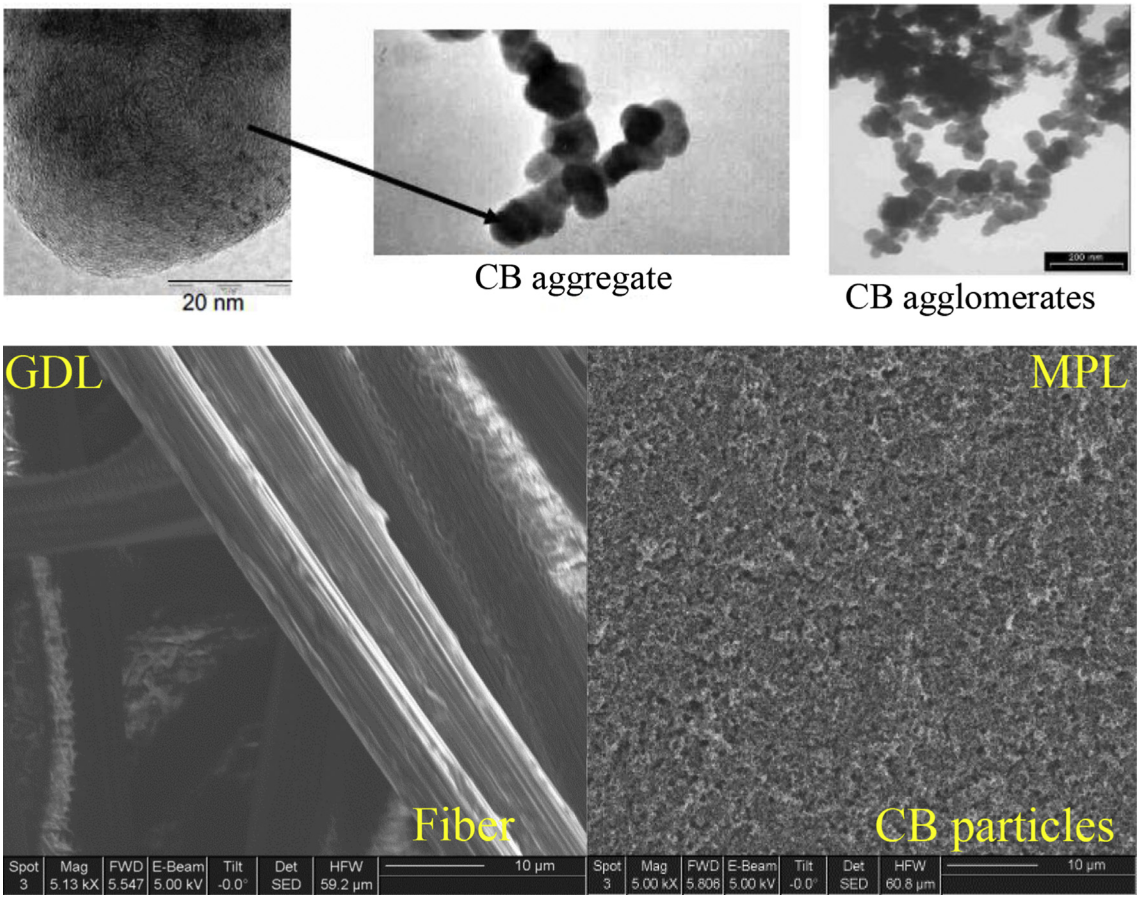

Fig. 1 – Images of an SGL MPL-GDL 24BC surfaces (present study) and MPL carbon black (CB) agglomerates, clusters and particles [25].