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Pd–NiO-Y/CNT nanofoam: a zeolite-carbon nanotube conjugate exhibiting high durability in methanol oxidation†

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A Pd–NiO-based catalyst hybridized with zeolite-Y and multiwalled carbon nanotubes has been found to show a remarkable mass activity in the electrochemical oxidation of methanol with long term durability up to 80 000 s.

The decrease in fossil fuels and their increasing adverse impact on the environment, causing global warming, has pushed researchers to think of an alternative source of clean energy.[1] In this context, the application of fuel cells in the production of electrical energy from chemical reactions with less emission of environmental pollutants is currently gaining skyrocketing importance.[2] Direct alcohol fuel cells (DAFCs) are presently considered to be highly efficient model systems for the production of electricity with efficiency comparable to those of gasoline and hydrocarbons.[3,4] Among the alcohols, methanol (CH_3OH) has gained special attention in DAFCs due to its low cost, good solubility, and easy transportation.[1,2] Most importantly, its energy density is close to that of gasoline.[4] The Pt-based catalysts are known to be highly active in DAFCs. But the real commercialization of Pt-based fuel cells has been restricted by carbon monoxide poisoning, high Pt-loading and their overall performance.[5] Therefore, the search for other transition metal based electrocatalysts giving high mass activity and durability is still an ongoing process. In this regard, Pd being in the same group and possessing similar activity like Pt has attracted the eyes of researchers due to its high catalysts.[4] In general, the support must have good conductivity and high surface area and should be stable and inert in working conditions.[4,7] Carbon-based materials are well known for such applications.[7] But still there remain challenges in improving the particle distribution and the durability of the catalyst and in retarding the CO poisoning with carbon-supported electrocatalysts. Zeolites in these aspects are considered to be highly beneficial as they possess good surface area and provide an environment to improve the activity of metals like Pd and Au for CO oxidation.[8,9] They also have considerable proton conductivity, are hygroscopic and are stable at high temperatures.[8] Various studies have shown that the incorporation of zeolite into the existing membranes like Nafion, commonly used as a membrane in DMFCs, blocks the pores in membrane matrices.[10] This in turn increases the diffusion resistance and reduces the alcohol crossover.[10] Because of such advantages, zeolites are hybridized with carbon-based materials to improve the efficiency and durability of the electrocatalyst. Sancho *et al.* combined a Nafion–zeolite membrane as a composite to decrease the alcohol crossover effects.[11] Similarly; Han *et al.* studied a zeolite composite membrane that exhibits stability at higher temperatures.[12]

Compared to other carbon materials, carbon nanotubes (CNTs) are considered to be a versatile hard templating agent as they can be tuned with different functional groups like –COOH, –NH_2, *etc.*, influencing the properties of the materials.[13,14] Very