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RESEARCH HIGHLIGHT

Metal–organic frameworks: The future of low-κ materials

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The rapid development of ultra-large-scale integration and the continuous miniaturization of integrated circuits toward the nanoscale require ultra-low dielectric constant (κ) materials to replace the traditional SiO_2 ($\kappa = 3.9$). Because air or a vacuum has the lowest dielectric constant ($\kappa = 1$), the partial replacement of solid materials with a vacuum represents a potential route for the development of the new low-κ materials required for future electronics.[1] Porous materials, particularly metal–organic frameworks (MOFs), can be utilized as future low-κ materials. As new low-κ materials, MOFs promise a next generation of dielectric materials for extremely stable, cheap, and mechanically flexible microelectronics devices.

MOFs have emerged as a promising class of materials with a variety of applications. Ordered frameworks with tunable functionalities, uniform pore sizes, post-synthesis modification, rich coordination chemistry and fascinating topologies result from the unique properties of MOFs that arise from the self-assembly of metal ions/clusters with electron-donating organic linkers.[2] On basis of these advantageous features, MOFs have been extensively studied over the past decade regarding their applications in gas storage, chemical separation, catalysis, proton conduction, drug delivery and biomedical imaging. However, an exploration of the dielectric properties is warranted due to the unique properties of highly porous MOFs that result from the rational self-assembly of organic linkers and inorganic metal ions/clusters.

The design of new MOFs with very low κ values is motivated by a brief theoretical study on the use of a thermally and mechanically stable series of MOFs as low-κ materials.[3] Further advances in experimental studies of low-κ MOFs have been reported in recent years. A number of MOFs exhibiting ultra-low κ values with low leakage current and good thermal/mechanical stability have been synthesized. A dehydrated strontium-based MOF exhibited a very low dielectric constant ($\kappa = 2.4$) with the highest thermal stability (420 °C) among all reported low-κ MOFs.[4] ZIF-8 films were deposited on silicon wafers and characterized to assess their potential as future low-κ materials. Because of the good coalescence of the crystals, good mechanical properties, absence of intergranular voids and hydrophobicity of the pores, an effective κ value of 2.33 was reported for these ZIF-8 films.[5] Figure 1 shows dielectric constants for some low-κ MOFs that adhere to the timescale for the development of future integrated circuits designs set by the International Technology Roadmap for Semiconductors.

On basis of the published literature, the future of MOFs as the next generation of low-κ materials is promising. To achieve a low-κ MOF, the introduction of ligands with few polar functional groups results in the incorporation of porosity in the structures. High dielectric solvents should be avoided, and in the case of polar guest molecules, the sample should be dehydrated. Anions with lower polarizability can be included to maintain a

Refs.	MOFs	κ
Chem. Mater. **25**, 27 (2013)	$\{(Zn(MeIM)_2\}$ (ZIF-8)	~2.33
J. Mater. Chem. C **2**, 3762 (2014)	$\{[Sr_2(1,3\text{-bdc})_2\}_n$	~2.4
Chem. Comm. **49**, 9248 (2013)	$\{[Pb(Tab)_2(4,4'\text{-bipy})](PF_6)_2\cdot 2MeCN\}$	~2.53
Cryst. Growth Des. **14**, 1572 (2014)	$\{[Zn_2(L\text{-trp})_2(bpe)_2(H_2O)_2]\cdot 2H_2O\cdot 2NO_3\}_n$	~2.53
Mater. Chem. **22**, 2398 (2012)	$\{Mn_2(D\text{-cam})_2(2\text{-Hpao})_4\}_n$	~2.8
Mater. Chem. **22**, 2398 (2012)	$\{[Co_2(D\text{-cam})_2\text{-}(3\text{-abpt})_2(H_2O)_3]_n\cdot 5nH_2O\}$	~3.0
Chem. Comm. **49**, 9248 (2013)	$\{[Pb(Tab)_2]_2(PF_6)_4]\cdot 2MeCN\cdot DMF\}$	~3.04

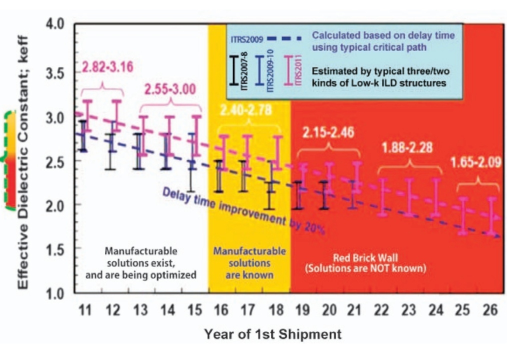

Figure 1 The reported dielectric constants (3.04–2.33) for MOFs adhere to the timescale for the development of future low-κ interlayer dielectric materials set by the International Technology Roadmap for Semiconductors (ITRS). Some MOFs have dielectric constants that meet the current standards for low-κ materials, and several current materials have dielectric constants low enough to meet future standards for low-κ materials, up to the year 2021 (ITRS graph has been copied from Baklanov *et al.*[6] Creative Commons license can be found at https://creativecommons.org/licenses/by-nc-nd/4.0/).

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low polarization. The emerging field of MOFs is promising for potential applications as future low-κ materials for the electronics industry.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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