Plasma-enabled methane conversion to hydrogen and nanocarbon materials

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Methane decomposition is a promising technology for CO_2-free hydrogen production that generates only solid carbon by-products. Methane decomposition is basically an endothermic and energy intensive process (Eq.1). The challenge to achieve methane conversion to hydrogen lies in the activation of C-H bond. The conventional process for methane activation often requires a high temperature over 700°C and pressure exceeding 10 bar [1]. Such harsh operation conditions result in large energy consumption and pose safety issues, hence limiting the use of stranded gas in practical fuel markets.

$$CH_4 \rightarrow 2H_2 + C, \Delta H^{\circ} = +75.6 kJ \cdot mol^{-1}, at\ 298\ K \quad (1)$$

Electron-driven technology, such as low temperature plasma (LTP), is an alternative solution for methane activation effectively. In the LTP process, the applied electric field causes the breakdown of gas molecules to generate highly reactive species. Excited electrons in the plasma regime own around 5-10 eV, therefore, ease the energy barrier for the dissociation for C-H bonds (4.3 eV) of methane [2].

Plasma-enabled methane decomposition offers a promising method for hydrogen production. However, this process encounters challenges including low methane conversion and hydrogen selectivity, catalyst deactivation, and low-value carbon by-products [3]. To address these issues, we proposed a novel approach integrating Ga-based liquid metal catalysts into a micro-bubble reactor with spark discharge. The liquid metal's high thermal conductivity, tunable surface reactivity, and fluidity synergistically enhance hydrogen selectivity (exceeding 80%). Notably, the liquid metal catalyst not only prevents deactivation but also directs the formation of high-purity, graphitic nanocarbon materials. The micro-bubble reactor optimizes energy efficiency to improve the methane conversion (over 40%), while nanosecond pulsed plasma activation ensures stable, high-performance operation. Systematic parameter optimization (plasma power, gas flow rate, catalyst composition) reveals critical insights into maximizing product yield and quality. This integrated strategy overcomes key drawbacks of conventional plasma-driven methane conversion, offering a new pathway for sustainable hydrogen production and value-added carbon nanomaterial synthesis.

References

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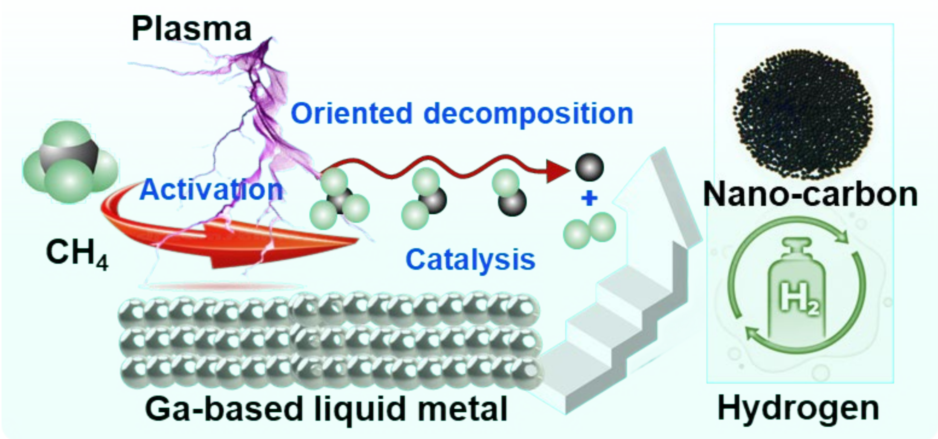

Figure 1. Plasma-enabled methane conversion to hydrogen and nanocarbon materials.