# Understanding Plasma-Material Interaction: From Fusion to Materials Processing

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## Abstract

Plasma-Material Interaction (PMI) is a critical phenomenon governing performance and reliability in both nuclear fusion environments and plasma-based materials processing. Understanding the underlying mechanisms of plasma-induced surface modification, hydrogen retention, and reaction kinetics is essential for advancing these technologies.

In context to nuclear fusion, understanding the interactions of plasma with wall material is crucial for recycling, fuel retention, and impurity production. Titanium has been used as wall coating material due to high solubility and fast diffusion. In this study, deuterium plasma exposures were carried out using the Ion-Gas-Neutral Interactions with Surfaces (IGNIS) facility to examine titanium-deuterium (Ti-D) interactions. The experiments were conducted over a range of ion fluence and surface temperatures to systematically evaluate deuterium uptake, retention, and release. In-situ diagnostics, including quadrupole mass spectrometry, X-ray photoelectron spectroscopy, and thermal desorption spectroscopy were employed to quantify desorption behavior and understand chemical composition changes. The results indicate that hydrogen retention is strongly influenced by ion fluence, surface temperature, and surface evolution, emphasizing the role of dynamic plasma-induced modifications in governing material response.

Building on these insights, hydrogen plasma has been further explored for the reduction of iron oxides as part of sustainable materials processing. Conventionally, iron-oxide reduction for iron and steelmaking rely on carbon-bearing gases, leading to significant carbon emissions. To reduce carbon footprint, alternate reductants such as hydrogen have attracted growing interest. In this work, plasma-assisted reduction of lower grade iron ore, taconite has been investigated using atmospheric pressure microwave-driven non-thermal hydrogen plasma. The presence of highly reactive plasma species, such as atomic hydrogen enhances reduction kinetics compared to conventional thermochemical processes. Parametric studies reveal that plasma conditions significantly influence reaction rates, enabling reduction at lower effective temperatures while improving efficiency.