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The Floating Aluminum Equipotential Extension Layer: A Multifunctional Inner Case for the Bulk-Equipotential Cell

The aluminum equipotential extension layer is a secondary inventive step of the Hydrogen-Aluminum Energy Cell disclosed in U.S. Provisional Application No. 64/055,649, a multifunctional inner case for a bulk-equipotential storage cell that holds charge as a continuous gel sitting at one uniform potential. A conventional enclosure introduces a potential boundary at its inner wall, and that boundary opens a slow capacitive leakage path through the enclosure dielectric. The filed provisional addresses this with an aluminum or aluminum-alloy inner layer that is electrically continuous around the entire interior wall, in Ohmic contact with the gel, and electrically isolated from both terminals by hermetic dielectric feedthrough seals. Because it is isolated from the terminals, the layer floats at the gel's bulk equipotential potential rather than being driven to either terminal, and in doing so it extends the equipotential volume to include the enclosure itself, eliminating the boundary and the parasitic-discharge pathway it would otherwise create. The same layer simultaneously serves as a Faraday cage, a self-passivating oxygen barrier, a chemically compatible inner surface, and a thermal-mass element.

The Boundary Problem in a Bulk-Equipotential Cell

The disclosed cell stores energy not at electrode interfaces but through bulk-equipotential saturation of a continuous gel medium, in which substantially all of the metal nanoflakes settle to a common potential and no internal potential gradient persists at rest. This storage principle depends on the absence of any internal potential boundary that could drive slow charge redistribution. A conventional enclosure works against that principle: where the gel meets the inner wall of an ordinary enclosure, a potential boundary forms at the enclosure inner surface, and that boundary admits slow capacitive leakage through the enclosure dielectric. The provisional identifies this as the principal external parasitic-discharge pathway. The aluminum equipotential extension layer is the disclosed structural answer, recited in Section 1.2 as a functional component of the bulk-equipotential charge retention principle rather than as a passive shell.

Floating at the Gel Potential

The innermost layer of the enclosure, in direct contact with the bulk gel volume, comprises an aluminum or aluminum-alloy layer (reference numeral 102). It is electrically continuous around the entire interior wall and is in Ohmic contact with the gel across substantially the full inner surface. The defining electrical feature is its isolation: the layer is electrically isolated from the first and second terminals by hermetic dielectric feedthrough seals at those terminals. Because it is never tied to either terminal, it is not driven to a terminal potential; instead it floats at the bulk-equipotential potential of the gel. Sitting at the gel's own potential, and being itself electrically continuous, the layer extends the equipotential volume of the cell to include the enclosure layer. The result, as the spec states, is that the potential boundary at the enclosure inner surface is eliminated, which removes the principal external parasitic-discharge pathway that would otherwise admit slow capacitive leakage through the enclosure dielectric.

Electromagnetic Shielding

The same layer functions as a Faraday cage isolating the cell interior from external electromagnetic fields. The provisional describes the mechanism in terms consistent with its equipotential role: external fields couple to the aluminum layer and induce surface charges, and those surface charges redistribute symmetrically across the continuous layer. Because the redistribution is symmetric, it does not couple asymmetrically to the gel interior and does not induce internal potential gradients that would drive parasitic charge redistribution. The shielding function and the equipotential function are therefore the same property viewed from outside and inside: a continuous conductor at a single potential.

The Self-Passivating Oxygen Barrier

The enclosure as a whole is configured to exclude molecular oxygen ingress to a partial pressure below approximately 10 parts per million within the cell interior across its operational lifetime. The aluminum layer contributes to this directly. Its outer-facing surface naturally passivates upon manufacture by forming a thin aluminum oxide (Al2O3) layer of approximately 2 to 10 nanometer thickness. That native passivation layer admits oxygen partial pressures below 10 parts per million through the enclosure wall across timescales characteristic of the cell's operational lifetime, and it does so without active oxygen-getter engineering. The barrier is, in other words, a property the material provides on its own rather than an added subsystem.

Inner-Surface Compatibility and Thermal Mass

While the outer face passivates, the inner-facing surface of the aluminum layer remains in a pristine metallic state by virtue of the reducing environment of the gel, in direct analogy with the way the metal nanoflakes are kept in their pristine state by that same reducing environment. The pristine inner surface is what preserves the Ohmic contact on which the equipotential extension depends. The layer also carries a thermal function: it admits thermal coupling between the cell interior and exterior, supporting heat dissipation during high-rate operation and admitting thermal management without separate engineering. These are the fourth and fifth functional contributions the spec assigns to a single piece of metal.

Dimensions and the Surrounding Multi-Layer Construction

The provisional gives the aluminum inner layer a thickness in the range of approximately 50 micrometers to 5 millimeters, with thinner ranges for small portable cells and thicker ranges for large stationary cells. Radially outboard of it, the enclosure may include one or more conventional outer layers: a carbon-fiber composite layer for mechanical impact resistance, vibration damping, and secondary structural integrity; a polymer-rubber compliance layer for mechanical strain absorption between the aluminum layer and the external environment; a metallized polymer layer for additional barrier function; and a consumer-facing finish layer for cosmetic, regulatory-marking, or thermal-radiative function. The spec is explicit that these outer layers are conventional engineering materials, require no exotic chemistry, and are selected per the deployment environment. Aluminum is recited as the preferred inner-layer material by virtue of its low atomic mass, low cost, abundance, natural passivation behavior, and inner-surface stability in the reducing gel environment, with copper, nickel, stainless steel, conductive ceramics, and conductive carbon-composites named as alternatives that provide equivalent equipotential, shielding, and barrier functions when given appropriate inner-surface compatibility coatings.

The Aluminum Leakage Degradation Mode and Its Liner

The disclosure is candid that the aluminum surface in contact with the gel can itself seed a long-timescale degradation pathway. Section 7.7A describes aluminum cations, which can arise in part from oxidation events at the inner surface of the equipotential extension layer, migrating to boron sites in the boron-doped carbon framework, where they are stronger Lewis acids than substitutional boron and can form aluminum borides and aluminum carbides that degrade the boron-doping precision multiplier. The spec characterizes this as a long-timescale mode and, on order-of-magnitude estimates, places the half-life of the boron-doping precision multiplier in the range of approximately 30 to 200 years at typical operating conditions, noting it does not affect near-term capacity, cycle life, or kinetic performance. To suppress it, Section 1.2A discloses a thin perfluorinated lubricant liner (reference numeral 104) at the interface between the aluminum layer and the gel, of approximately 0.1 to 5 micrometers thickness. The liner interrupts direct contact between the aluminum metal and the boron-doped carbon framework, preventing both the formation of aluminum cations at the case-gel interface and the migration of carbon framework species into the aluminum lattice, while remaining thin enough to retain the ionic permeability and electronic tunneling that keep the equipotential function intact. Additional mitigations the spec lists include maintaining the gel's reducing environment to reduce transient cations back to metallic aluminum, an aluminum-cation-binding chelating agent, selection of an alternative inner-surface material, and physical separation of boron-doped regions from the case interface.

Service and Reuse

Because the layer is a defined material element rather than a sacrificial coating, the provisional treats it as a recoverable component. The gel can be cast into the aluminum enclosure during manufacture, and at end of service the aluminum equipotential extension layer of the enclosure is among the materials the spec describes being inspected, resurfaced, and reused, alongside regeneration and reincorporation of the gel constituents. The same enclosure that defines the cell's equipotential volume is thereby framed as part of the cell's serviceable, reusable architecture.

Disclosure Scope

This article describes subject matter disclosed in U.S. Provisional Application No. 64/055,649. It is a technical summary of the disclosed aluminum equipotential extension layer and its associated structures and is not a claim construction, a legal opinion, or a representation of scope beyond what that application discloses. Every mechanism, dimension, and outcome stated here is drawn from the filed specification; no figures, properties, or performance values have been added.

Hydrogen-Aluminum Energy Cell (/h-al-battery)

All 40 steps → (/inventive-steps)

Sealed electrochemical cell storing energy as reversible covalent hydrogen bonds on carbon electrodes.

Provisional application

PRIMARY TECHNICAL DISCLOSURE

- A Hydrogen-Aluminum Surface-Bond Storage Cell with Bulk-Equipotential Charge Retention (/articles/a-hydrogen-aluminum-surface-bond-storage-cell-with-bulk-equipotential-charge-retention)

SECONDARY TECHNICAL

- Charge Retention by Bulk-Equipotential Saturation Without an Internal Separator (/articles/h-al-battery/bulk-equipotential-charge-retention)
- Storing Energy as Electron-Stabilized Metal-Hydrogen Surface Bonds Formed by Proton-Coupled Electron Transfer (/articles/h-al-battery/hydrogen-metal-surface-bond-storage)
- Electron-Mediated Bond Stability: The Kinetically Trapped Idle State Behind Indefinite Calendar Life (/articles/h-al-battery/electron-mediated-bond-stability)
- Hot-Proton Charging Versus Cold-Proton Discharge: The Bias-Gated Asymmetry That Blocks Self-Charge and Self-Discharge (/articles/h-al-battery/hot-cold-proton-asymmetry)
- Asymmetric Dual-Domain Proton Paths: Separate Ingress and Egress Routes in a Hydrogen-Aluminum Storage Gel (/articles/h-al-battery/asymmetric-dual-domain-paths)

- Hydrophobic Gating: Rejecting Neutral and Molecular Hydrogen While Admitting Only Biased Protons (/articles/h-al-battery/hydrophobic-gating)
- The Storage Gel as a Polarized Electrochemical Switch: Coherent Alignment, Equipotential Locking, and Load-Proportional Discharge (/articles/h-al-battery/gel-polarized-switch)
- Flake-Flake Electrostatic Isolation: DLVO Repulsion as a Self-Discharge Barrier in a Separator-Free Hydrogen-Aluminum Cell (/articles/h-al-battery/flake-electrostatic-isolation)
- Dynamic Flake Expansion: Carbon-Intercalation Wedging to Expose Buried Metal Surface Under Bias (/articles/h-al-battery/dynamic-flake-expansion)
- Hydrogen-Locked Expanded State: Surface-Energy Inversion as a Positive-Feedback Capacity Mechanism (/articles/h-al-battery/hydrogen-locked-expanded-state)
- Secondary Carbon-Hydrogen Storage on Transmuted Intercalated Carbon (/articles/h-al-battery/secondary-carbon-hydrogen-storage)
- Mechanochemical Strain Self-Healing and Use-Positive Aging in a Bulk-Equipotential Hydrogen-Aluminum Cell (/articles/h-al-battery/mechanochemical-self-healing)
- Boron Doping of the Carbon Framework as a Multi-Function Precision Multiplier (/articles/h-al-battery/boron-doping-precision-multiplier)
- **The Floating Aluminum Equipotential Extension Layer: A Multifunctional Inner Case for the Bulk-Equipotential Cell (/articles/h-al-battery/aluminum-equipotential-extension-layer)**

Hydrogen-Aluminum Energy Cell overview → (/h-al-battery)