MAGRON | Ferrofluid Technical Note

Why Is Vapor Pressure Data Important?

Vapor Pressure of Ferrofluids in Ultra-High Vacuum and Its Impact on Process Quality & Reliability

For CVD · Sputtering · Ion Implantation · Etching · OLED processes

Executive Summary

Semiconductor and display equipment **typically operate in ultra-high vacuum on the order of 10^{-6} Pa**. The vapor pressure of the ferrofluids, lubricants and sealants used inside the chamber **directly governs process cleanliness and yield**. A material with high vapor pressure evaporates and outgasses under vacuum, causing thin-film contamination, pattern defects, and yield loss.

For this reason, it is essential to **define a vapor-pressure SPEC for the material and substantiate it with measured data (TGA-based) and validated models (Langmuir & Arrhenius)**. This document explains why — with a focus on data and rationale.

1. Why Is Ultra-High Vacuum Required?

Key semiconductor processes (CVD, Sputtering, Etching, etc.) are generally performed in high / ultra-high vacuum at **the 10^{-6} Pa level or below**. The purpose of raising the vacuum level is clear:

- **Minimizing contaminants —** lowering the density of gaseous contaminants such as moisture, organic residues and oxygen prevents impurities from adsorbing and bonding onto the wafer surface.
- **Securing the mean free path —** deposition and etching species reach the surface without colliding with other molecules, ensuring film quality and directionality.
- **Maintaining surface cleanliness —** once adsorbed, impurities do not readily desorb even under high vacuum, so selecting a **low-vapor-pressure material from the outset** is critically important.

In other words, cleanliness is not determined by pump capacity alone. The **self-outgassing of the materials inside the chamber** sets the practical limit on the achievable vacuum level and the resulting process quality.

2. Correlation Between Vapor Pressure and Process Quality

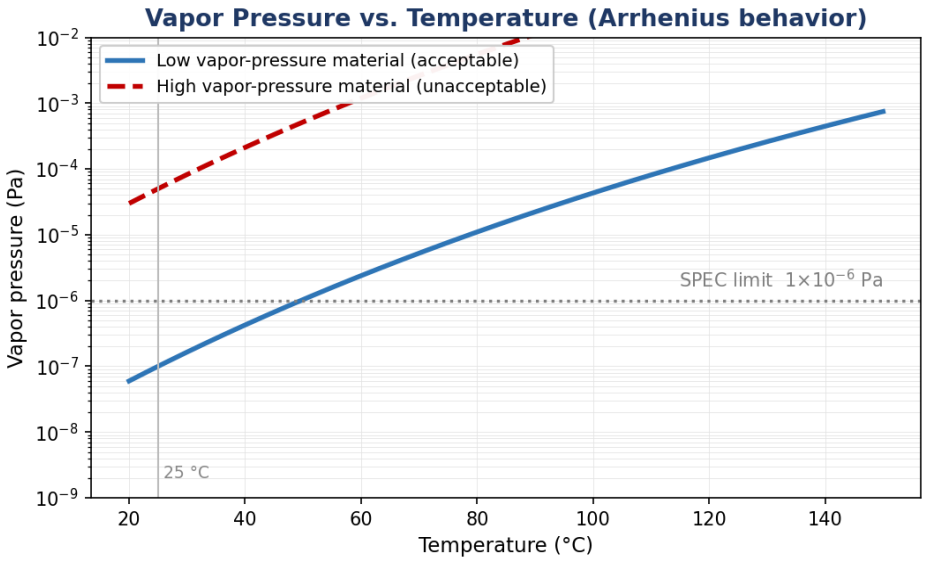
A material with high vapor pressure evaporates easily under vacuum and contaminates the

chamber interior. In particular, **ion implantation and OLED deposition** must maintain a stable, low vapor pressure even in environments at or below 1×10^{-6} Pa.

If the vapor-pressure SPEC is not controlled, the following quality problems arise in a chain:

Observed phenomenon	Impact on process & quality
Particle growth	Evaporated molecules re-condense on cold surfaces and form particles → circuit short / open defects
Pattern contamination	An adsorbed contamination layer degrades lithography / etch precision → larger critical-dimension (CD) variation
Poor film uniformity	Contaminants interfere with the deposition reaction → non-uniform thickness / composition, degraded interface properties
Yield loss	Accumulation of the above defects lowers the good-die ratio per wafer → a direct increase in cost

The chart below compares the **temperature-dependent vapor pressure of a low- vs. high-vapor-pressure material** under identical conditions. The high-vapor-pressure material already exceeds the SPEC limit (1×10^{-6} Pa) by a wide margin at room temperature.



[Figure 1] Vapor pressure vs. temperature — only the low-vapor-pressure material stays below the SPEC limit

3. Required Vacuum Levels by Process

The required vacuum level and vapor-pressure sensitivity differ by process. The table below lists typical operating vacuum levels and the importance of vapor-pressure control for representative processes.

Process	Typical operating vacuum	Importance of VP control
Sputtering	10^{-4} – 10^{-6} Pa	High — directly tied to target / chamber cleanliness
CVD	10^{-3} – 10^{-6} Pa	High — film composition & interface quality
Etching	10^{-3} – 10^{-5} Pa	Medium — prevents re-deposition of residues
Ion Implantation	10^{-6} Pa or below	Very high — sensitive to beamline contamination
OLED deposition	10^{-5} – 10^{-7} Pa	Very high — organic purity & device lifetime

** Values are typical process ranges and may vary with equipment and recipe.*

4. Why the Vapor-Pressure SPEC Matters

Materials used inside a vacuum — ferrofluids, lubricants, sealants — must have a clearly defined **maximum vapor-pressure SPEC at a specified temperature**. For example, a quantitative criterion such as adopting only materials with **a vapor pressure of 1×10^{-6} Pa or less at 25 °C** is required.

Why a SPEC is needed

- **Quantitative pass/fail —** materials are screened against a measurable numerical criterion, not the qualitative term “low vapor pressure.”
- **Captures temperature dependence —** vapor pressure rises exponentially with temperature, so the SPEC must be defined at the actual use temperature.
- **Guarantees lot-to-lot consistency —** continuously meeting the same SPEC secures the reproducibility and supply reliability of mass-production quality.

5. How Is Vapor-Pressure Data Obtained and Validated?

Low-vapor-pressure materials have values too low to measure directly with an ordinary pressure gauge. Instead, we use a validated method that **measures the rate of mass loss (evaporation rate) under vacuum** and derives the vapor pressure from it.

5.1 TGA-based evaporation-rate measurement

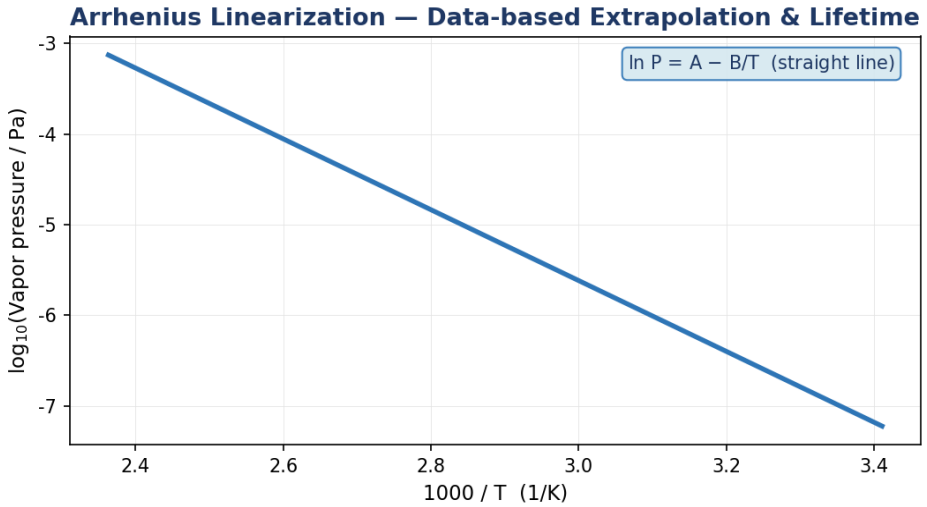
Vacuum thermogravimetric analysis (TGA) measures the mass-loss rate per unit area and time. This is the standard approach for the vapor pressure of non-volatile substances; the measured evaporation rate is converted to vapor pressure using the **Langmuir (Hertz–Knudsen) equation**.

$$P = (dm/dt) \cdot (1/\alpha) \cdot (2\pi RT / M)^{1/2}$$

P: vapor pressure, dm/dt: evaporation rate per unit area, α: evaporation coefficient (≈ 1 in vacuum), R: gas constant, T: absolute temperature, M: molar mass

5.2 Arrhenius-model extrapolation & lifetime prediction

Vapor pressure follows **Arrhenius (Clausius–Clapeyron) behavior** of the form ln P = A − B/T. By linearizing data measured at several temperatures against 1/T, the vapor pressure at the actual use temperature can be reliably **extrapolated**, and long-term evaporative loss and lifetime can be predicted.



[Figure 2] Arrhenius linearization — extrapolating vapor pressure at the use temperature from measured data

5.3 Verification documents provided to the customer

- **Vapor-pressure chart —** temperature-resolved vapor-pressure curve based on measured TGA data
- **Lifetime prediction —** long-term evaporation / lifetime estimate at the use condition, derived from the Arrhenius model
- **Calculation basis —** the derivation and assumptions per the Langmuir equation, stated explicitly

** Reference: the U.S. aerospace/semiconductor outgassing standard (ASTM E595) requires TML ≤ 1.0% and CVCM ≤ 0.10% under 125 °C / 24 h, and serves as an international benchmark for selecting low-vapor-pressure materials.*

6. Conclusion & Customer Value

The reliability of semiconductor and display equipment is governed by the stability of materials under ultra-high vacuum.

- A low-vapor-pressure material is **the key to high-quality thin-film formation and high-reliability processes**.
- Quantitatively setting and managing the vapor-pressure SPEC **prevents particles, pattern contamination, poor uniformity, and yield loss**.
- Through **measured vapor-pressure data (TGA) and validated models (Langmuir & Arrhenius)**, we objectively demonstrate quality reliability and process suitability to our customers.

Vapor-pressure data is not merely a material property — it is the evidence that guarantees the customer's yield and equipment reliability. A low-vapor-pressure material proven by data is one that can be adopted with confidence.