

Solubility and dilution of MO sources

For each kind of metal organic source, there are source mass flow controller (MFC) and push MFC. Generally, the solubility of typical metal organic precursors in H₂ or N₂ gases is much larger than the vapor pressures of metal organic precursors. The MO source carrier gas flows into the bubbler to transport metal organic precursors in vapor phase. After that, the MO push gas dilutes the mixture of carrier gas and metal organic precursor. Run MO and push MO gases further dilute the mixture by flowing more H₂ or N₂ into the gas line. Due to the dilution, the metal organic precursors will not precipitate and contaminate the gas line or the reaction chamber. **Fig. 1** shows the gas flow schematic of metal organic precursors.

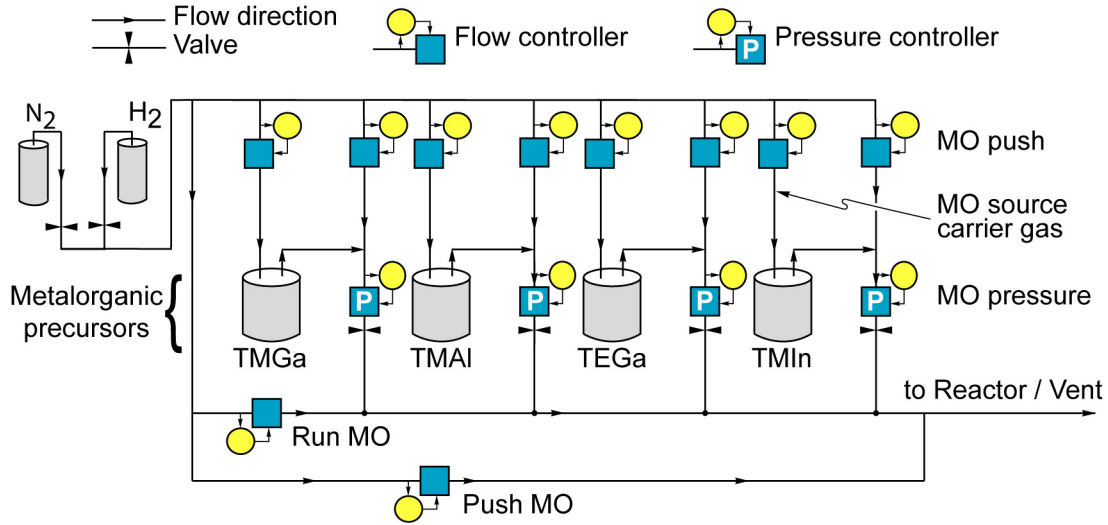


Fig. 1: Gas flow schematic of MO sources

The vapor partial pressure of metal organic precursor depends on temperature. The relation can be expressed as

$$P_{\text{partial}} = 10^{(a - b/T)} \times \frac{1013.25}{760} \text{ mbar}$$

Table 1 gives the values of parameters *a* and *b* for common metal organic precursors (after < www.epichem.com >).

	<i>a</i>	<i>b</i> (K)	Vapor partial pressure (mbar)
TMGa	8.07	1703	90 (0 °C)
TMAI	8.22	2134	9.60 (17 °C)
TEGa	8.08	2162	5.62 (17 °C)
TMIn	10.52	3014	1.78 (17 °C)

Table 1: Vapor partial pressures of common metal organic precursors (after < www.epichem.com >).

Relation between molar flow rate and volume flow rate

Recall the ideal gas equation, $PV = nRT$, where P is pressure, V is volume, n is number of moles, R is the ideal-gas constant, $R = 8.316 \text{ J}/(\text{mol K})$, and T is the temperature. Using the ideal-gas equation, the molar metal organic (MO) precursor flow can be expressed as

$$\Phi_{M,MO} = \frac{P_{\text{partial, MO}}}{RT} \Phi_{V,MO} = 0.0446 \frac{\text{mmol}}{\text{cm}^3} \frac{P_{\text{partial, MO}}}{P_{\text{total}}} \Phi_{V,\text{total}}$$

where $\Phi_{M,MO}$ is the molar flow rate of the MO precursor (given in moles per minute), $\Phi_{V,MO}$ is the volume flow rate of the MO precursor (given in sccm), $P_{\text{partial, MO}}$ is the vapor partial pressure of the MO precursor (given in mbar), P_{total} is the total pressure of the gas mixture, i.e. the sum of the partial pressure of the carrier gas plus the partial pressure of the MO precursor gas, $\Phi_{V,\text{total}}$ is the total volume flow rate of the gas mixture (given in sccm). In most cases, the partial pressure of the MO precursors are much smaller (more than 2 orders of magnitude) than the partial pressure of the carrier gas. Hence, two approximations can be made

$$P_{\text{total}} \approx P_{\text{partial, carrier}} \quad \text{and} \quad \Phi_V = \Phi_{V,\text{total}} \approx \Phi_{V,\text{carrier}}$$

where $P_{\text{partial, carrier}}$ is the partial pressure of the carrier gas (given in mbar), $\Phi_{V,\text{carrier}}$ is the volume flow rate of the carrier gas (given in sccm).

For TMGa source at 1013 mbar and 0 °C:

$$\Phi_{M,MO} = 0.0446 \frac{\text{mmol}}{\text{cm}^3} \frac{90 \text{ mbar}}{1013 \text{ mbar}} \Phi_V = 3.96 \times 10^{-3} \frac{\text{mmol}}{\text{cm}^3} \Phi_V = 3.96 \times 10^{-3} \frac{\text{mmol}/\text{min}}{\text{sccm}} \Phi_V$$

For TMAI source at 1013 mbar and 17 °C:

$$\Phi_{M,MO} = 0.0446 \frac{\text{mmol}}{\text{cm}^3} \frac{9.6 \text{ mbar}}{1013 \text{ mbar}} \Phi_V = 4.27 \times 10^{-4} \frac{\text{mmol}}{\text{cm}^3} \Phi_V = 4.27 \times 10^{-4} \frac{\text{mmol}/\text{min}}{\text{sccm}} \Phi_V$$

For TEGa source at 1013 mbar and 17 °C:

$$\Phi_{M,MO} = 0.0446 \frac{\text{mmol}}{\text{cm}^3} \frac{5.62 \text{ mbar}}{1013 \text{ mbar}} \Phi_V = 2.47 \times 10^{-4} \frac{\text{mmol}}{\text{cm}^3} \Phi_V = 2.47 \times 10^{-4} \frac{\text{mmol}/\text{min}}{\text{sccm}} \Phi_V$$

For TMIIn source at 1013 mbar and 17 °C:

$$\Phi_{M,MO} = 0.0446 \frac{\text{mmol}}{\text{cm}^3} \frac{1.78 \text{ mbar}}{1013 \text{ mbar}} \Phi_V = 7.84 \times 10^{-5} \frac{\text{mmol}}{\text{cm}^3} \Phi_V = 7.84 \times 10^{-5} \frac{\text{mmol}/\text{min}}{\text{sccm}} \Phi_V$$

How can molar flow rates be reduced or increased?

The molar flow rate can be reduced or increased in the following ways:

- **Change of MO source volume flow rate $\Phi_{V, \text{total}}$ (first choice)**

Note: This is the regular way. However, due to the limitation of the MFC, the molar flow rate has a lower and upper limit. The lower limit of our MO source MFC is 1.0 sccm. The upper limit of our MO source MFC is 100 sccm.

- **Change of MO source carrier gas pressure (second choice)**

Note: The common MO pressure we use is 1000 mbar. The dynamic range of MO pressure controller is limited to between about 100 mbar and 2000 mbar. Note that the molar flow is inversely proportional to the MO source carrier gas. Thus, based on this pressure range, the molar flow rate could be decreased by a factor of 2 and increased by a factor of 10.

- **Change bubbler temperature (third choice)**

Note: Change of bubbler temperature will change the MO partial pressure. Generally the bubbler temperature should be kept constant (TMAI: 17 °C; TMGa: 0 °C; TEGa: 17 °C; TMIn: 17 °C). It will take a long time for the bubbler temperature to be stable. It is practically impossible to change the bubbler temperature during growth.

- **Hardware modification (fourth choice)**

Note: A double dilution stage allows one to further reduce the volume flow rate (and molar flow rate) of a MO source gas.