INTRODUCTION: WHY JET VAPOR DEPOSITIONS?

What could you expect from Jet vapor support?

- Sonic jet can impart significant amounts of kinetic energy to the impinging molecules, which can enhance their ability to diffuse and incorporate into the lattice.
- Process benefits
  - high GPC
  - reduced substrate temperature deposition
- Reactor conditions
  - scalable to large area

 # Jet: Is a concentrated stream

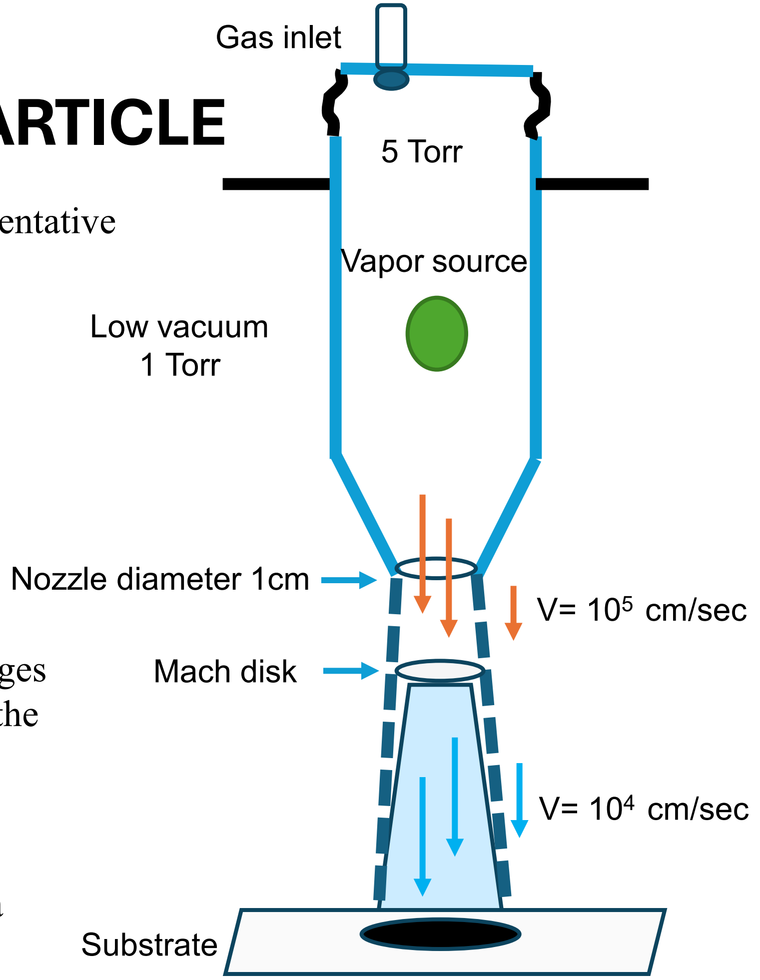
A FEW HIGHLIGHTS FROM AN ARTICLE

A generalized "jet in low vacuum" JVD source showing representative operating conditions

Both jet velocity and density change at the Mach disk, but the jet remains nearly cylindrical

When the ratio $P_n/P_d > 2$, the flow is "critical," and the jet emerges at its maximum velocity, the speed of sound; for He at 298 K, the exit velocity is ~ 10^5 cm/s.

The jet can convey any atomic, molecular, or cluster vapor to a substrate for condensation as a film.



As soon as the jet exits the nozzle, it expands into a zone of reduced density in which nearly all atoms move in the same direction at the speed of sound. This zone is collision free; it terminates at the Mach disk, located a distance $x \sim 0.67\, D_n (P_n/P_d)^{1/2}$ downstream of the nozzle of diameter D_n. In JVD the usual pressure ratios lie in the range $2 < P_n / P_d < 10$, and the Mach disk is located several nozzle diameters, or several cm, downstream.

B. I. Halpern and J. J. Schmitt
Jet Process Corporation, 25 Science Park, New Haven, Connecticut 06511
J. Vac. Sci. Technol. A, Vol.12, No.4, Jul/Aug 1994

Our motivation

T. P. Ma, "Making silicon nitride film a viable gate dielectric", *IEEE Trans. Electron Devices*, 45, 680 (1998).

«The JVD process utilizes a high-speed jet of light carrier gas to transport the depositing species onto the substrate to form the desired films.

…

The breakdown characteristics of the JVD nitride are also respectable. Compared to their MOSFET counterparts, MNS transistors exhibit reduced low-field transconductance but enhanced high-field transconductance, perhaps due to the presence of border traps. As expected, the JVD silicon nitride films exhibit very strong resistance to boron penetration and oxidation at high temperatures. These properties, coupled with its room-temperature deposition process, make JVD silicon nitride an attractive candidate to succeed thermal SiO_2 as an advanced gate dielectric in future generations of ULSI devices. »

Journal of The Electrochemical Society, **155** (2) G21-G28 (2008)
0013-4651/2007/155(2)/G21/8/$23.00 © The Electrochemical Society

ECS

Low-Temperature SiO_2 Layers Deposited by Combination of ECR Plasma and Supersonic Silane/Helium Jet

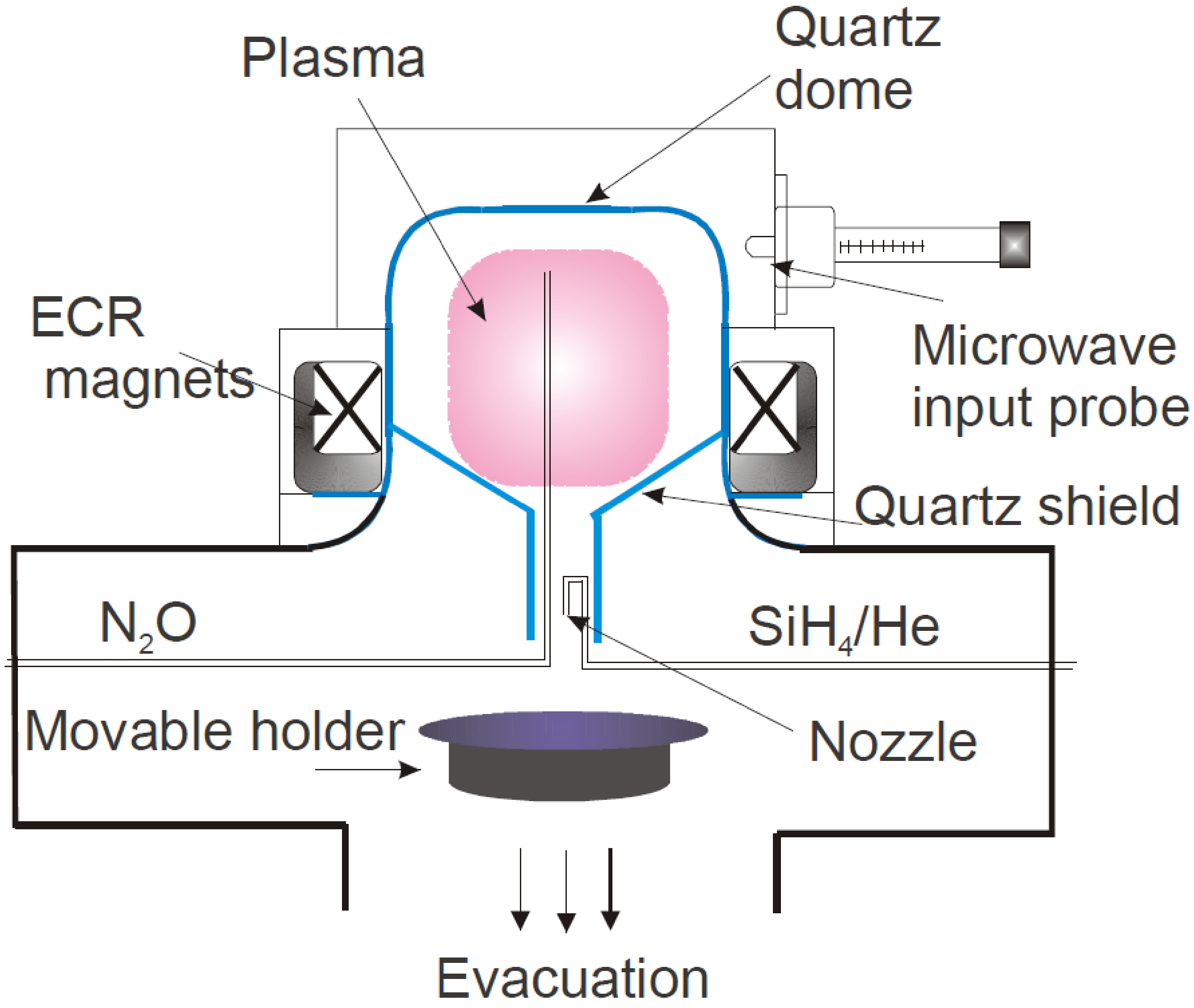
Alexey Y. Kovalgin,*,z Gratiela Isai, Jisk Holleman, and Jurriaan Schmitz

MESA+ Institute for Nanotechnology, University of Twente, 7500 AE Enschede, The Netherlands

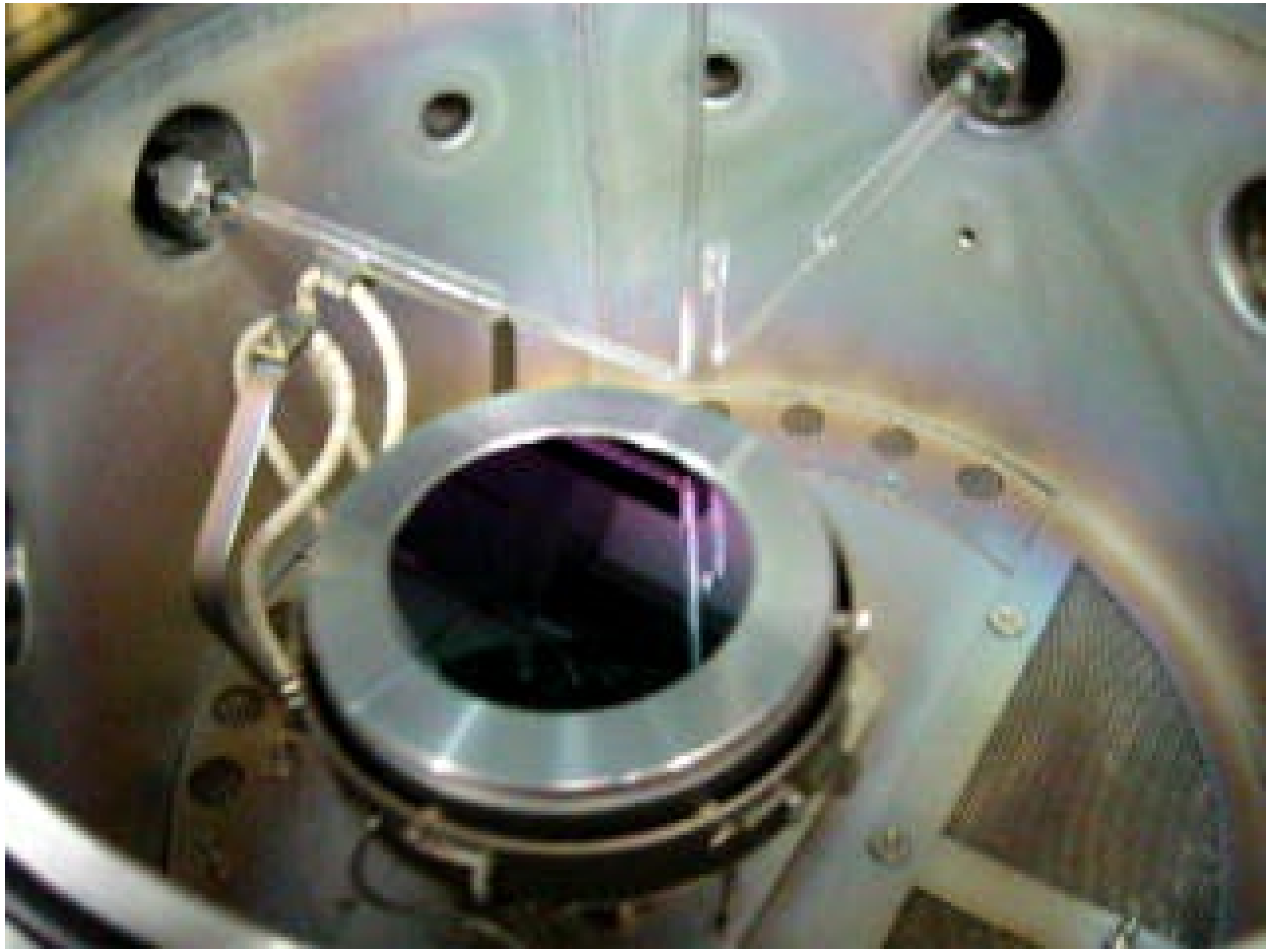
ECR-JVD reactor

Floating substrate *T*, no active heating

Nozzle = just a small hole in a quartz tube, no shape control

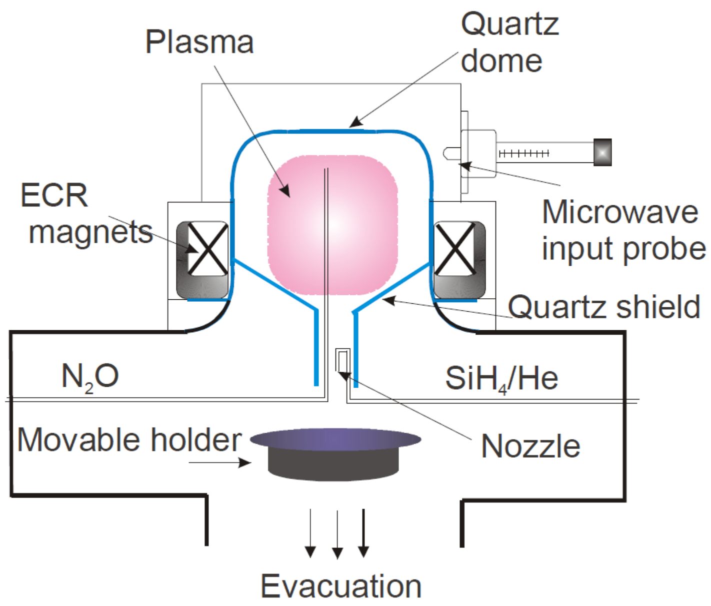


Improving film uniformity



Effect of the Jet (I)

Plasma off, room *T* => observed deposition rate of approx. 0.3 nm/min



To theoretically confirm that oxygen-containing layers can be deposited by the high-speed jet, the following considerations are done. It is assumed that SiH_4 molecules and He atoms have similar velocities in the jet (Fig. 3). For a SiH_4 molecule, a velocity of 1000 m/s corresponds to a kinetic energy of ~0.17 eV, which is much less than the lowest activation energy (E_a) required for the dissociation of silane ($SiH_4 + M \rightarrow SiH_2 + H_2 + M$; $E_a = 2.2$ eV and M is a third body, which is the wafer surface in this case). However, such a low energy can still result in a measurable dissociation rate, if the collision frequency of the molecules with the surface is sufficiently high. For deposition conditions listed in the caption to Fig. 8, the calculated SiH_4 flux (F_{SiH_4}) to the wafer surface is in the order of 10^{18} molecules $cm^{-2}\ s^{-1}$ (assuming a spot diameter of 1 cm on the surface). The dissociation rate of silane (R_{SiH_4}), obtained from the Arrhenius expression $R_{SiH_4} = F_{SiH_4}\ \exp(-2.2/0.17\ eV)$, is then in the order of 10^{12} molecules $cm^{-2}\ s^{-1}$. For a sticking probability of 1 for SiH_2 radicals, this will result in a deposition rate in the order of 10^{14} Si atoms per min (approximately one monolayer) and is in agreement with the measured deposition rate.

Effect of the Jet (II)

After post-metallization annealing at 400 °C for 5 min.