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Towards a Carbon Nanotube Ionization Source for Planetary Atmosphere Exploration

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Technology Objective

A carbon nanotube electron gun (CNTEG) is constructed for the highly sensitive exploration of exospheres, i.e., extremely tenuous atmospheres ($n < 10^8 \text{ cm}^{-3}$). The CNTEG is based on the quantum principle of field emission$^1$ seeking to efficiently impact and therefore ionize diffuse neutrals known to be present around planetary bodies.

Exosphere Ionization

Goal: To simulate & design ideal ionization volume demonstrating ion production via $e$ impact.

1) Electric force balance: $\frac{d}{dt}(n_e,v_e)=dQ$
2) Poisson's equation (space-charge): $\frac{d^2}{dx^2}v_e=\rho_f$
3) Electron-impact ion production rate $dn_e/dt=\sigma v_e n_0$

Europe's Hydro-Exosphere

Overall water exosphere is uniform in 1D, H$_2$ detection excess $H_2/\frac{\text{flux}}{\text{area}}$ may be an anomaly.

Sub-Jovian water is more than 10x dense at high altitudes.

Fig. 5: Side view of water ($\phi = 30^\circ$) & molecular oxygen ($\phi = 90^\circ$) simulation and observation.

Fig. 6: Top view of simulated atomic oxygen exosphere.

Fig. 7: View of simulated atomic oxygen exosphere.

Carbon Nanotubes as Cold Cathodes

Fig. 3 SIMION simulation of CNTEG electronics’ equipotentials and e trajectories. *Grids are at 50% transparency.

Fig. 4: CNTEG emission field measured at each electrode labeled above.

• CNTEGs are emitting consistently at ~ 90%.
• Anode emission is at 76%.
• Emission $=100\mu$A is achieved with a cathode gate distance of $d_{cg}=250\mu$m.

Fig. 8: Selected SIMION simulation of ionization volume demonstrating ion production via $e$ impact.

Fig. 1 CNTG:
• Electron field effect emission generates current due to solid-state quantum tunneling$^1$.
• Moderate $E$ field. ($E<1$MV/m).
• Power-efficient. (P $<0.1$ Watts).
• Sufficiently powerful current ($I \sim 800$ nA $.1 \mu$A).
• Very stable.
• $d/dt < 0.1$ $\mu$A/s.
• Light-weight and robust.

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Results

Extended Exosphere Clouds are simulated, due to:

• Jovian gravitational drag is evident.
• Similar to sodium clouds at Io$^5$.
• Escape rates could indicate an Enceladus-like hydrotorus.

Perspectives from Surface-Exosphere inhomogeneties:

• Sputtering may not be global$^7$.
• $O_+, S_+$ ions may not dominate$^8$.
• Water-product escape rates match previous studies$^9$.
• $O_2$ is thermized to $T_{ex}$, speeds are not sufficient to populate upper exosphere.

References:
1. Foster & Nordheim, 1038. PRL 28 (1972)

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