Neutral Atom Lithography Using a Bright Metastable Helium Beam

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Bright He* Beam

Use a reverse flow He discharge source[1] to create metastables.

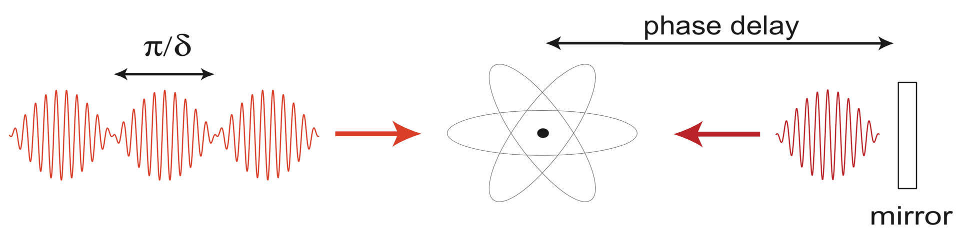
The source produces He* atoms with v_c=1000 m/s and a flux of ~$0.5*10^{14}$ atoms/sr s.

The beam is collimated sequentially by the bichromatic force and optical molasses. The collimation stages use only 10 cm of the atomic beamline.

The detected signal corresponds to a peak current of $3*10^8$ atoms/s through and aperature of area of 0.1 mm^2. The collimated beam has a full width half max of 3.5 mm at 33 cm from the source; and was measured to have a divergence angle of 7.5 mrad.[2]

Intuitive Approach:

Pi-Pulse Model of the Bichromatic Force



pi-pulse condition: $\Omega_r = dE_o/\hbar = \pi\delta/4$ and $s \sim 2(\delta/\gamma)^2$

pi-pulse train: $E(z,t) = E_o\cos[(k\pm\Delta k)z - (\omega_A\pm\delta)t]$

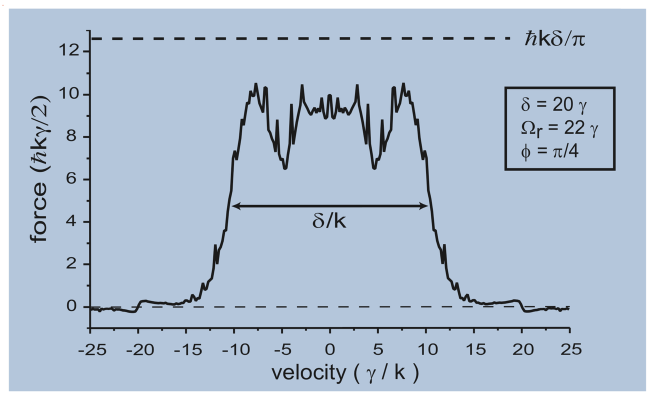
Basic ideas:

- controlling the momentum exchange between light field and atom by timing of counter-propagating pi-pulses (phase condition)
- de-excitation process is stimulated not spontaneous emission

Magnitude of the Bichromatic Force

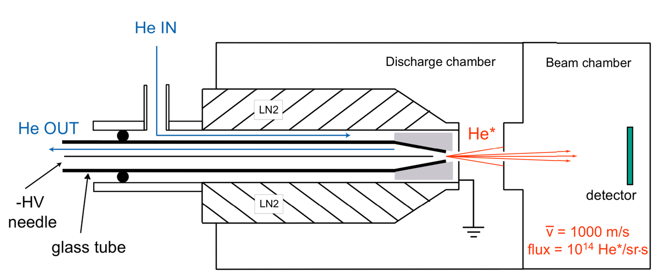
Instantaneous value $\rightarrow F = \frac{\Delta p}{\Delta t} = \frac{2\hbar k}{\pi/\delta}$ (not limited by γ !)

Averaged value (spont. em., phase) $\rightarrow \bar{F} = \frac{\hbar k\delta}{\pi} >> \frac{\hbar k\gamma}{2}$ (huge compared to scattering force)



The force profile F(v) is calculated exactly by numerical evaluation of the Optical Bloch Equations

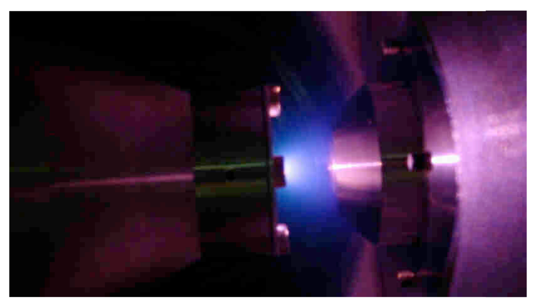
He* DISCHARGE SOURCE



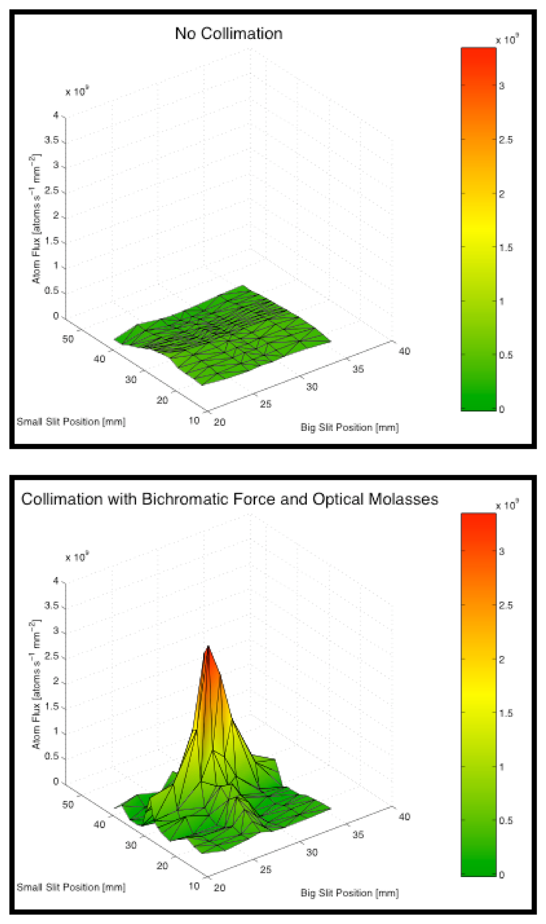
Reverse Flow Design

J. Kawanaka et al., Appl. Phys B 56 21 (1993).

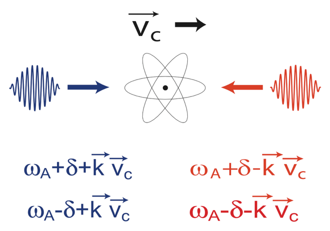
PHOTO OF He* DISCHARGE SOURCE



Atomic Beam Profiles

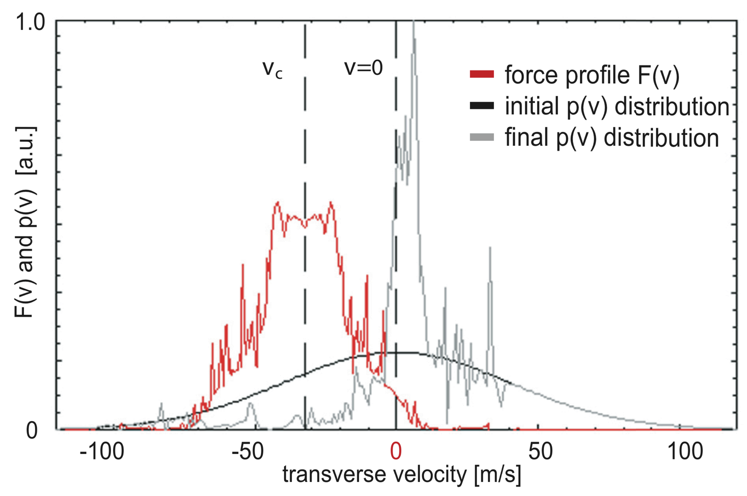


Shifting the Center Velocity of the Force



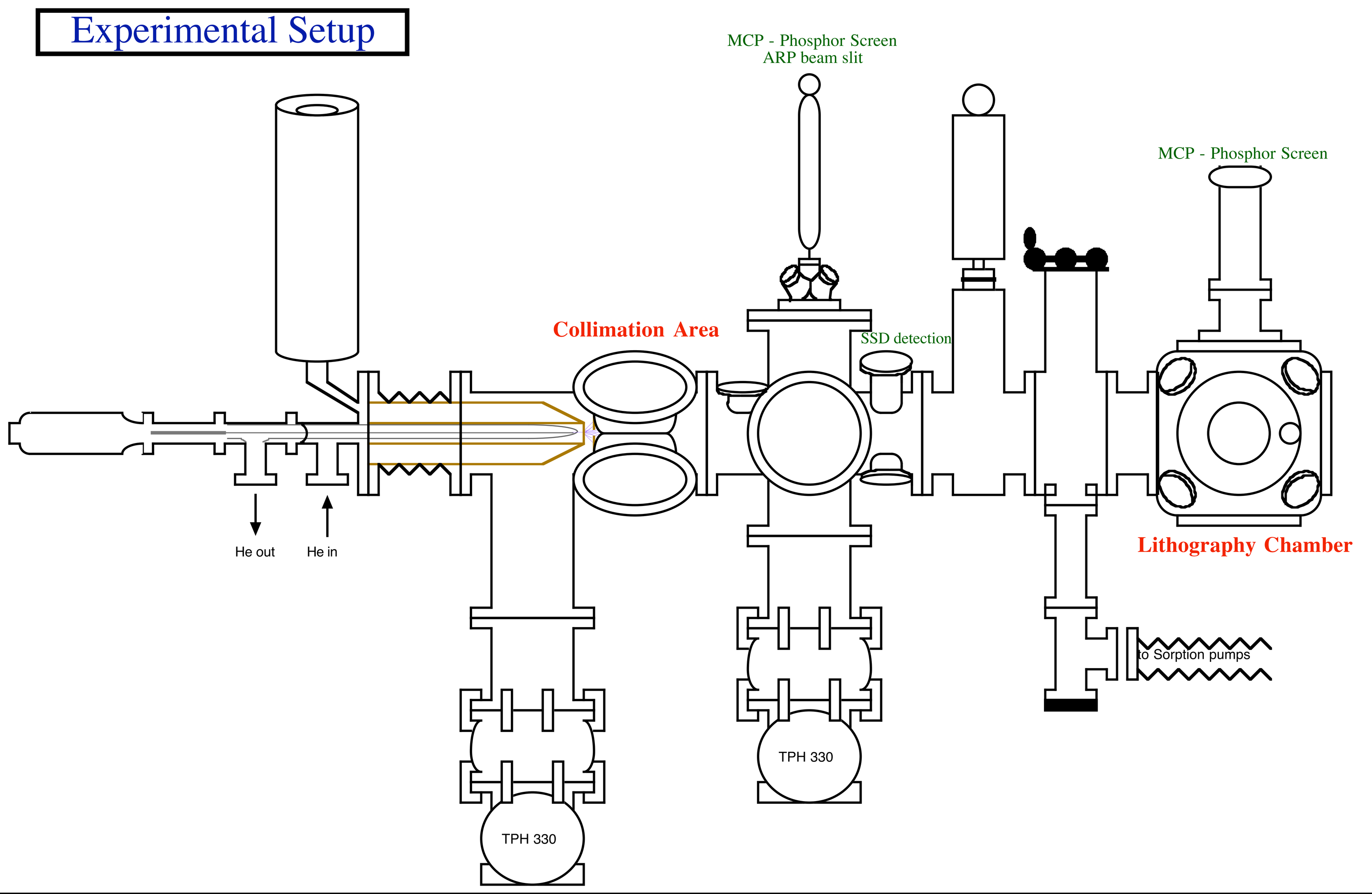
For moving atoms the counterpropagating pi-pulse trains need to be detuned by $\vec{k}\vec{v}$ to compensate Doppler-shift:

$$\boxed{\vec{k}\,\Delta\vec{v} = \hbar\,\Delta\omega}$$



Above: Shifted force profile F(v) and simulated transverse velocity distribution p(v) of He* beam before and after one interaction region

Experimental Setup



Atomic Lithography with a Mechanical Mask

Place a fine Copper mesh (2000 mesh -- 12μm periodicity) over the coated wafer. The uncovered parts are exposed to the He* beam.

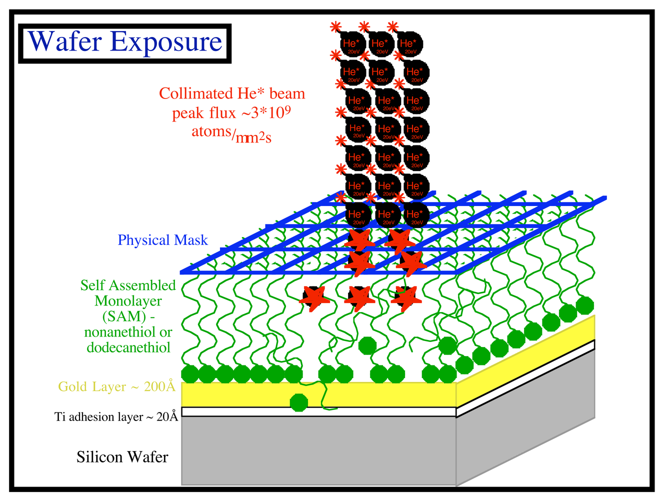
He* has 20eV of internal energy which destroys the thiol molecules of the SAM on impact.

Damaged SAM molecules leave underlying gold layer susceptible to a standard wet chemical etch[3]:

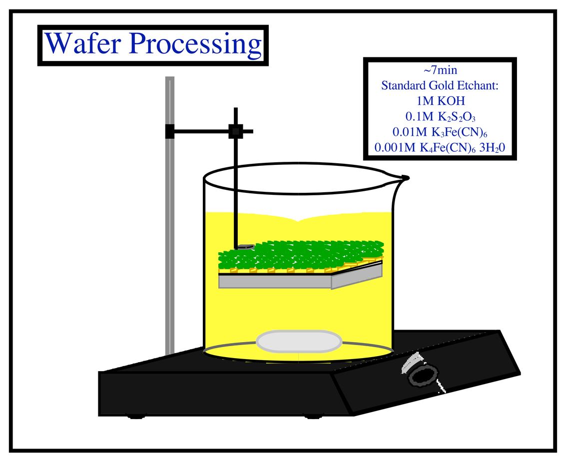
1M	KOH
0.1M	$K_2S_2O_3$
0.01M	$K_3Fe(CN)_6$
0.001M	$K_4Fe(CN)_6\ 3H_20$

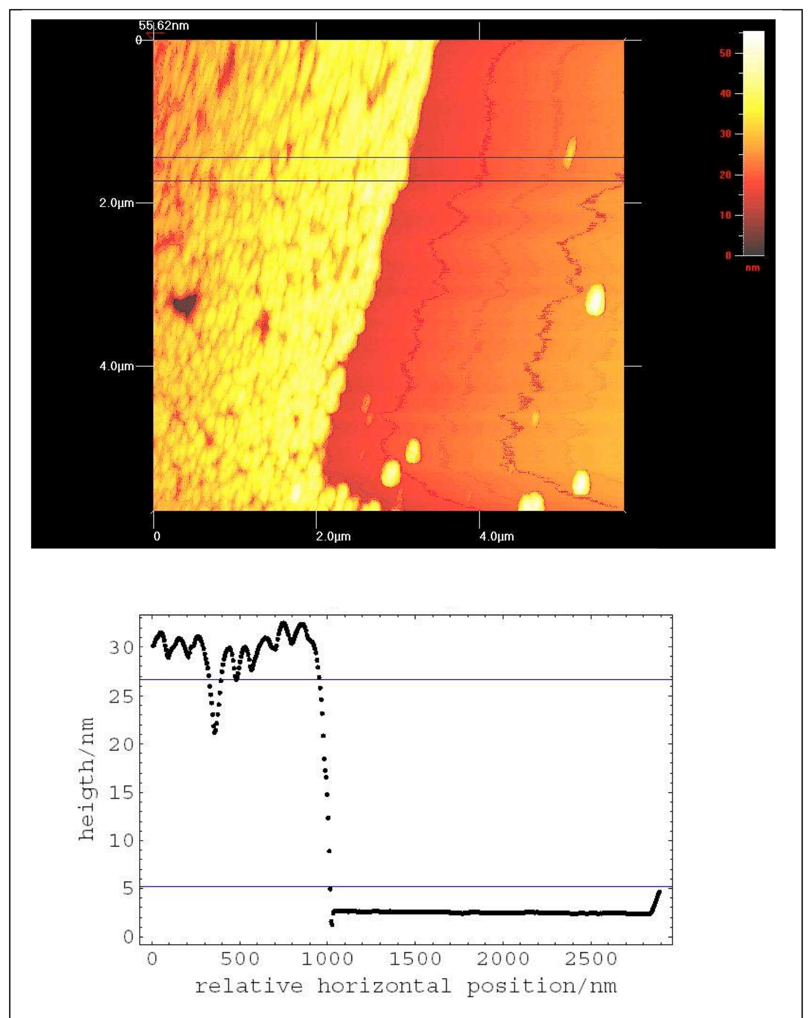
Electrochemical Etch Process:
Metal Oxidation
$Au^0+2S_2O_3^{2-}=Au(S_2O_3)_2^{3-}+e^-$
Reduction of oxidizer
$Fe(CN)_6^{3-}+e^-=Fe(CN)_6^{4-}$

Wafer Exposure



Wafer Processing





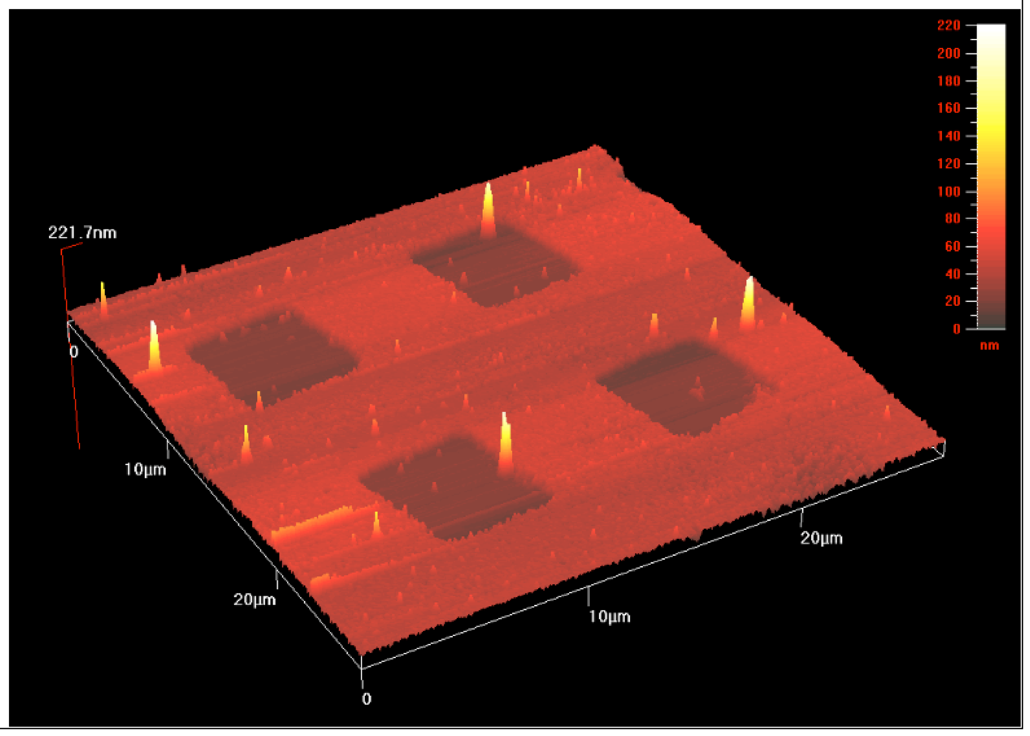
Results

Edge resolution of 63nm.

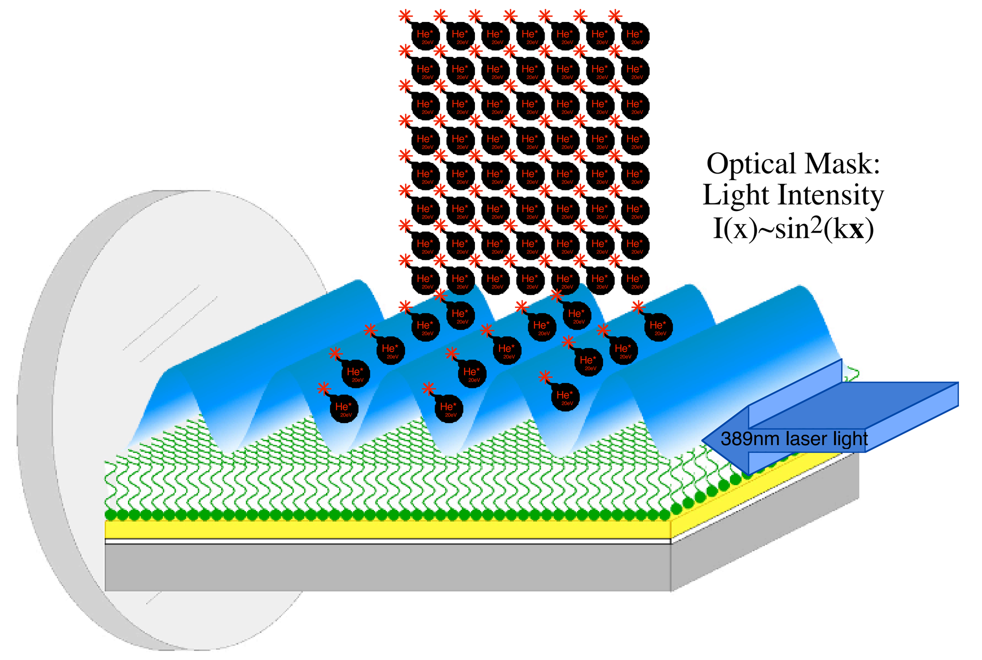
Dosage at beam peak: $2.8*10^{12}$ atoms/mm^2.

Assuming ~$10a_0^2$ effective area of alkanethiol molecule on surface, we have an exposure dose of 0.59He* atoms per resist molecule.

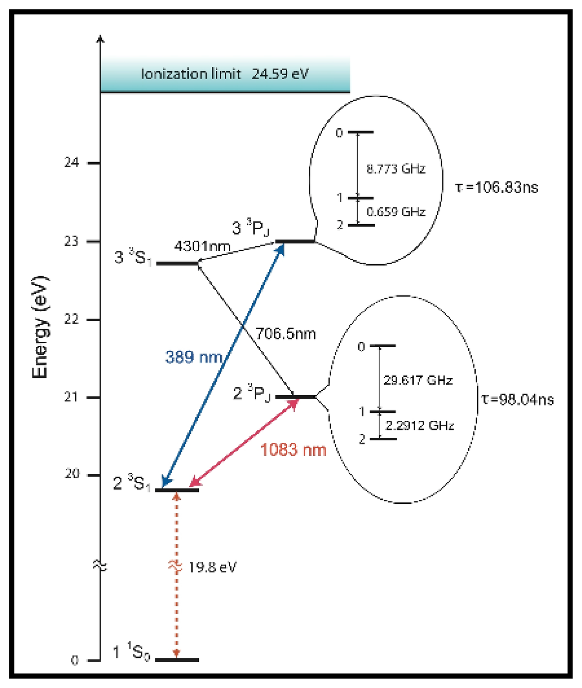
AFM Scan of Exposed Wafer



Future Plans



Optical Mask:
Light Intensity
$I(x)\sim\sin^2(kx)$



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Further Reading

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