Atomistic Modeling of Nitride Devices

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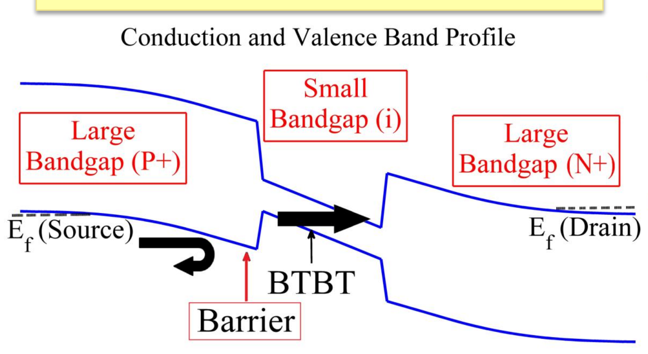
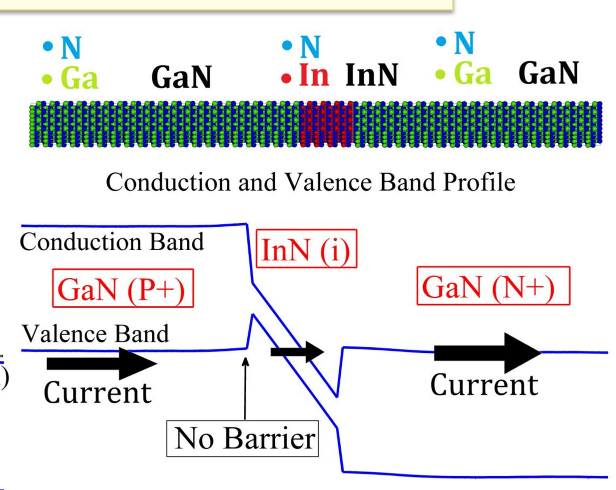
Why GaN/InN/GaN?

Why GaN/InN/GaN is a good candidate for Tunnel FET?

1. Large internal electric field
   - Large band-bending over small distance
2. Small band gap InN
3. Both GaN and InN are direct Band-Gaps (BG)
   - Tunneling through direct BG is more than indirect ones

Conventional hetero-structures



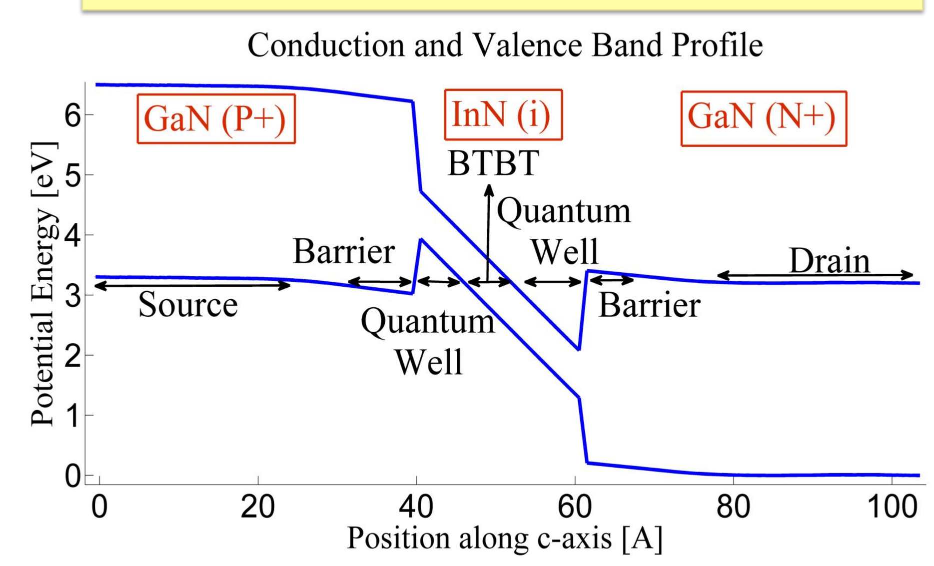


Atomistic Tight Binding Simulation of Nitrides:

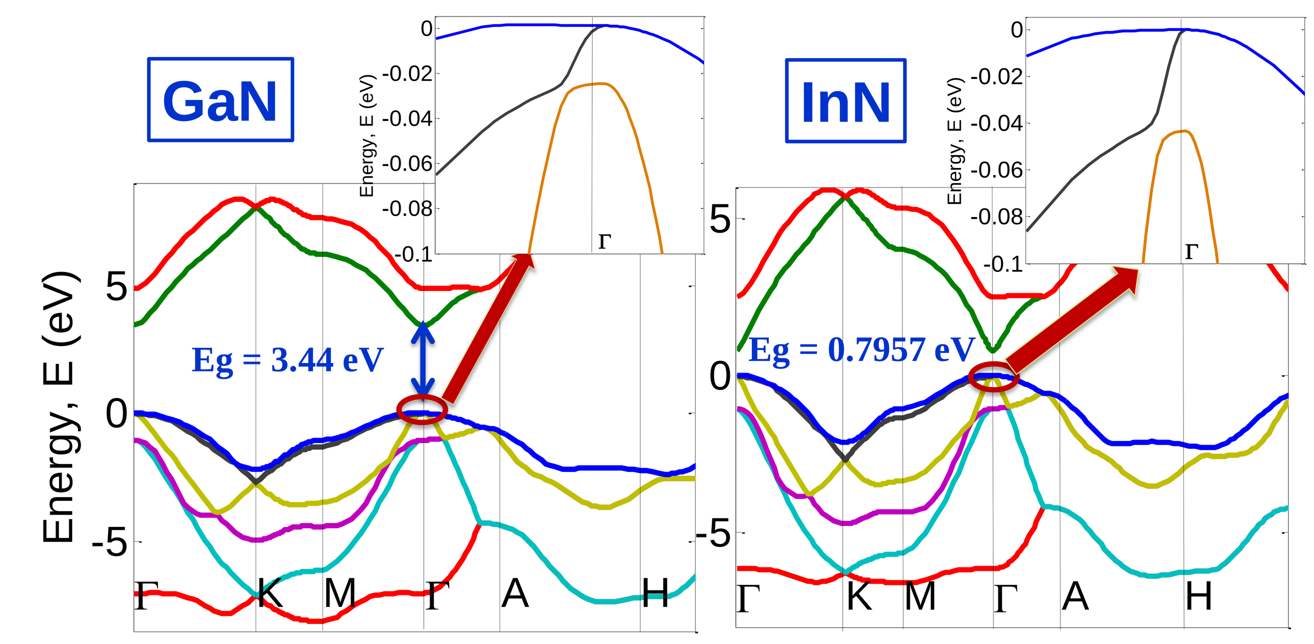
Atomistic Tight-Binding simulation of Nitride TFET
It is Not just Band To Band Tunneling (BTBT)

1. Barriers may appear near source and drain
2. Quantum wells and BTBT region in InN

Interesting features in the output characteristics



Tight binding band-structure of InN and GaN



Atomistic tight binding captures the effects of

- Crystal-field splitting
- Spin-orbit coupling

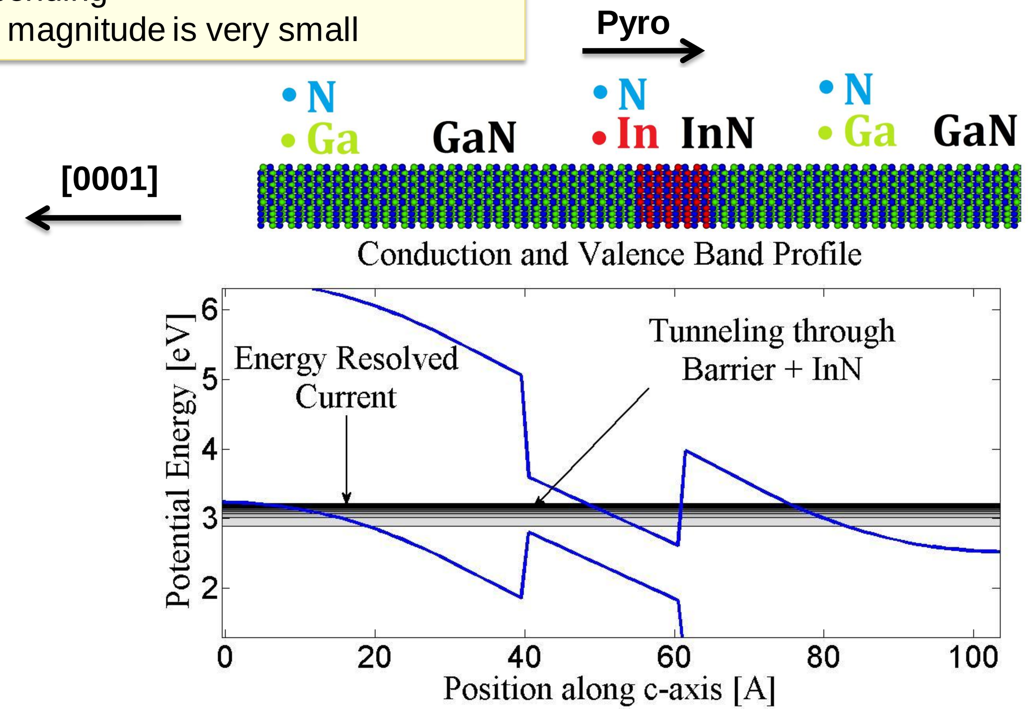
Ga-Face Growth

2nm Long InN (Ga-Face Growth)

1) Pyro field is against built-in PN junction field
2) The electric field is not large enough to make band bending
3) Tunneling magnitude is very small

PN Junction Built in field

Pyro



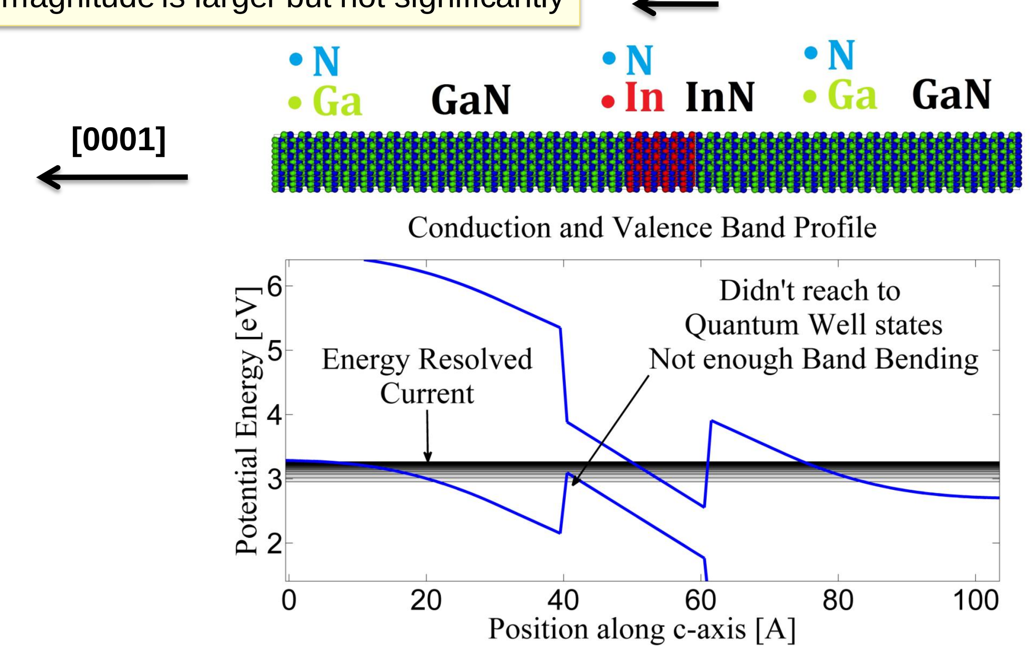
N-Face Growth

2nm Long InN (N-Face Growth)

1) Pyro field adds up to built-in PN junction field
2) The electric field is not large enough to make band bending
3) Tunneling magnitude is larger but not significantly

PN Junction Built in field

Pyro



Piezoelectric effect

Piezoelectric effect (Parameters [1])

1) E(Piezo) ~ 15 x E(Pyro) in InN
2) E(Piezo) is larger than 1V/nm
3) Huge band bending

[1] J. Phys.: Condens. Matter 14 (2002) 3399–3434

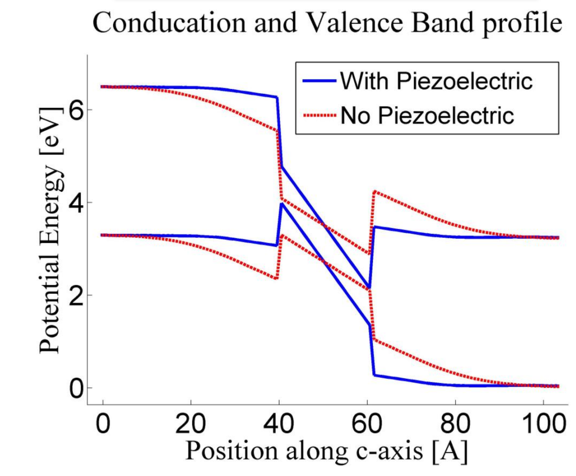
Piezoelectric

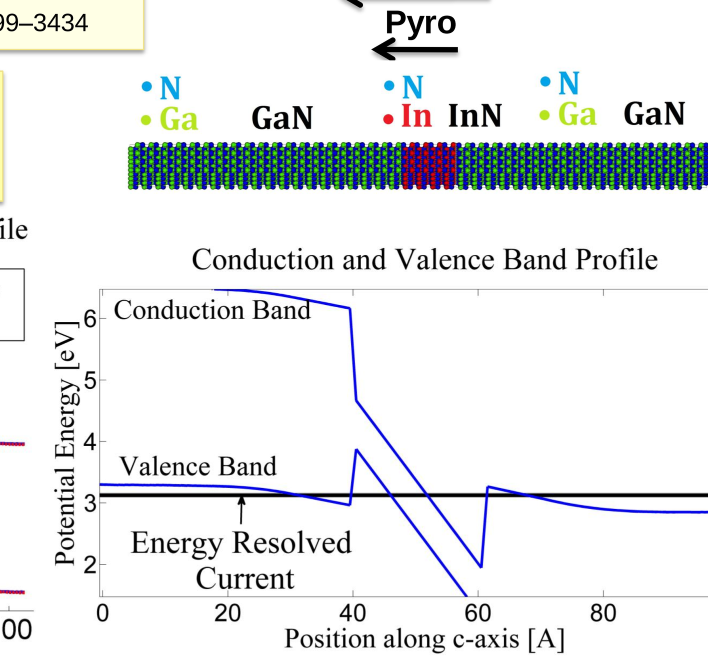
PN Junction Built in field

Pyro

Parameters:

1) P(Piezo) = 0.15 C/m^2
2) 1.5nm InN thickness





Piezoelectric effect

Piezoelectric effect (Parameters [2])

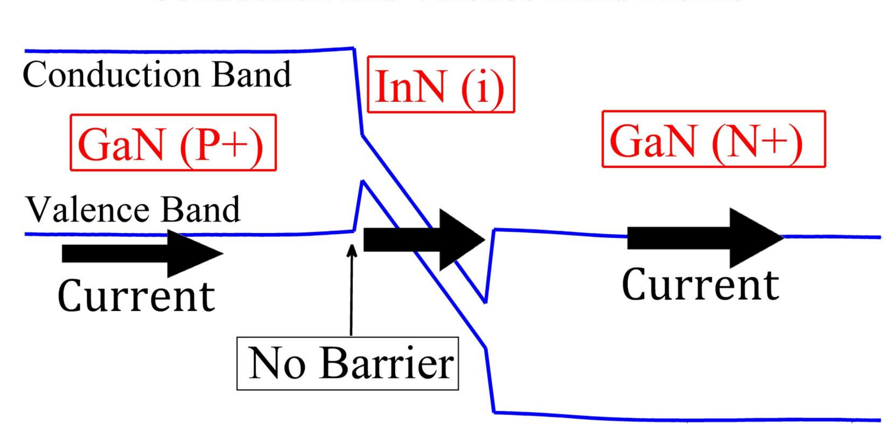
1) No barrier to reach BTBT region
2) E(Piezo) ~ 25 x E(Pyro) in InN
3) E(Piezo) is larger than 2V/nm

[2] Phys. Rev. B 56 (1997), R10024-R10027

Parameters:

1) P(Piezo) = 0.25 C/m^2
2) 1.5nm InN thickness

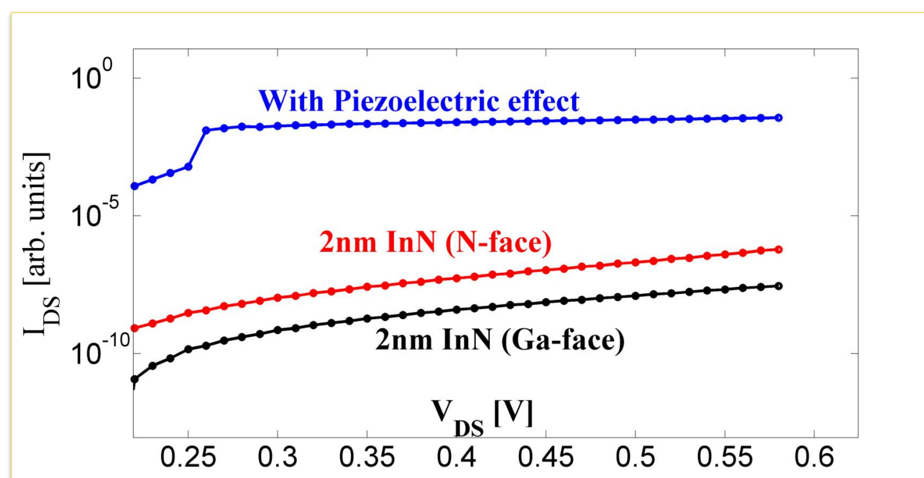
Conduction and Valence Band Profile



Output characteristics

The device structure needs to be engineered
Goal: tunneling through the low gap region
Problem: barriers to reach to the low gap region
Solution: piezoelectric effect can lower the barriers down to zero

Piezoelectric effect has the most important impact on the performance



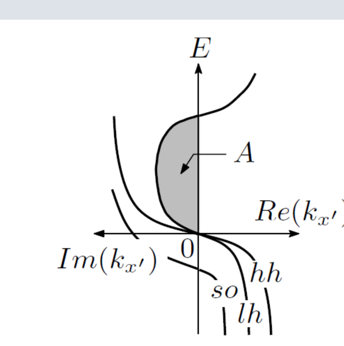
InN complex band-structure

Most probable BTBT minimizes the area $A = \int_{Ev}^{Ec} Im\{K\} dE$

BTBT Probability $T = e^{-\frac{2A}{qF}}$,

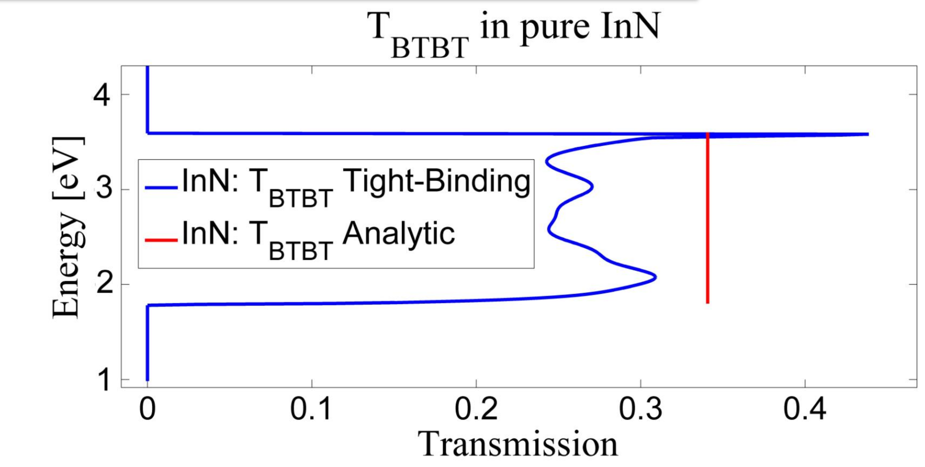
F = Electric field in depletion region

For pure InN, $T_{BTBT} = e^{-\frac{0.07}{F}}$, F= E-field(V/A°)



from Arvind Ajoy's PhD Thesis

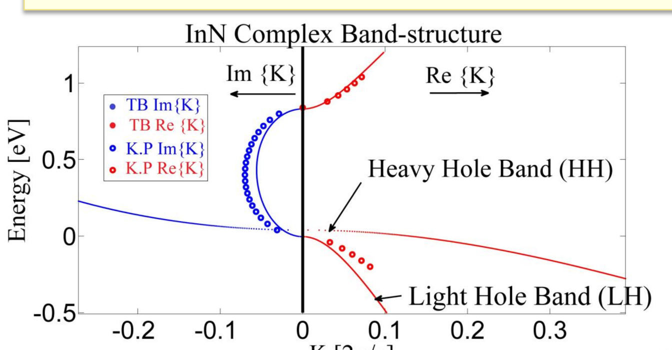
T_{BTBT} in pure InN



Complex Band Structure of InN

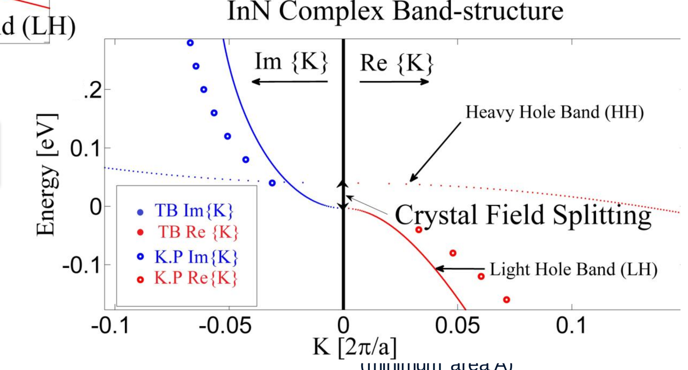
- Heavy Hole and Light Hole band splits due to crystal field splitting
- Light Hole band plays important role (minimum area A)

Crystal field splitting makes the effective band-gap larger (0.79➡ 0.84 eV)



$m_c^* = 0.068\ m_0$
$m_v^* = 0.13\ m_0$
$E_g = 0.795\ eV$
$E_g^{eff} = 0.84\ eV$

Tight Binding (TB) versus K.P



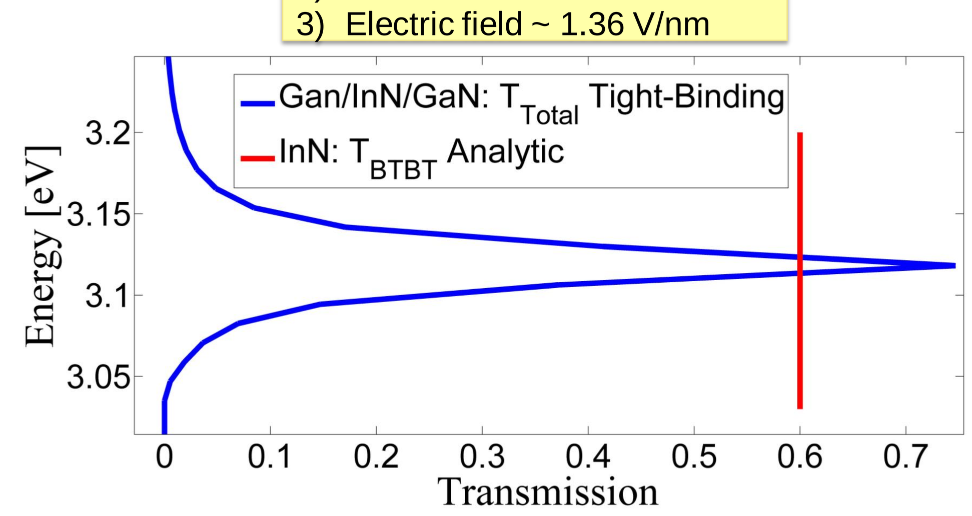
Band To Band Tunneling Probability in GaN/InN/GaN

Tunneling probability in GaN/InN/GaN is not much lower than InN

Small reduction in Transmission due to Barriers

Parameters:

1) P(Piezo) = 0.15 C/m^2
2) 2.0nm InN thickness
3) Electric field ~ 1.36 V/nm



Conclusion

Using self consistent Poisson-NEGF*, we studied GaN/InN/GaN

- The effect of Ga-Face and N-Face growth on the band profile was analyzed
- The piezoelectric effect studied with 2 different parameter sets
- Complex band structure of InN calculated using Tight Binding and K dot P
- Simple analytic equation for Band To Band Tunneling through InN devised
- The analytic equation verified against numerical simulation

GaN/InN/GaN is shown to be a good candidate for Tunnel FETs

***NEGF:** Non-Equilibrium Greens Function

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