Desorption and Sputtering on Solid Surfaces by Low-energy Multicharged Ions

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1. Background

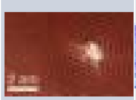
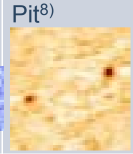
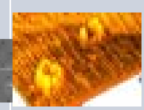
Sputtering and desorption on solid surfaces induced by slow multicharged ions have been attracting attention because of

1. high sputtering yield and its strong charge state (or potential energy) dependence as well as weak kinetic energy dependence, and following
2. nanostructure formation in every ion impact.

1-1. Sputtering and desorption

	OES	SIMS					Quartz Micro-balance
Species	H*	H^+		O^+ Ti^+	Si^+	$(UO_x)_y^+$	Total
Substrate	$Si(100)/H_2$	Si(100) 1×1 H[1] Si(111) 1×1 H[2]	SAM(MUD A and DDT)	$TiO_2(100)$	Si(111) 1×1 H[2]	U	LiF[3] NaCl[4] SiO_2[3]
Projectiles	Xe^{q+} $6 \le q \le 22$	Xe^{q+} $4 \le q \le 12$ I^{q+} $17 \le q \le 53$	Ar^{q+} $4 \le q \le 10$	I^{q+} $25 \le q \le 51$	I^{q+} $17 \le q \le 53$	Au^{q+} $36 \le q \le 69$ Xe^{q+} $17 \le q \le 52$	
Yield	$\sim q^{2.8 \pm 0.3}$	$\sim q^5$ $\sim q^{3.4}$	$\sim q^5$		$\sim q^{1.4}$		
Authors	Deiwiks (2006)	1) Kuroki (2003) 2) Tona (2006)	Flores (2009)	Tona (2008)	Tona (2006)		3) Sporn (1997) 4) Varga (1997)

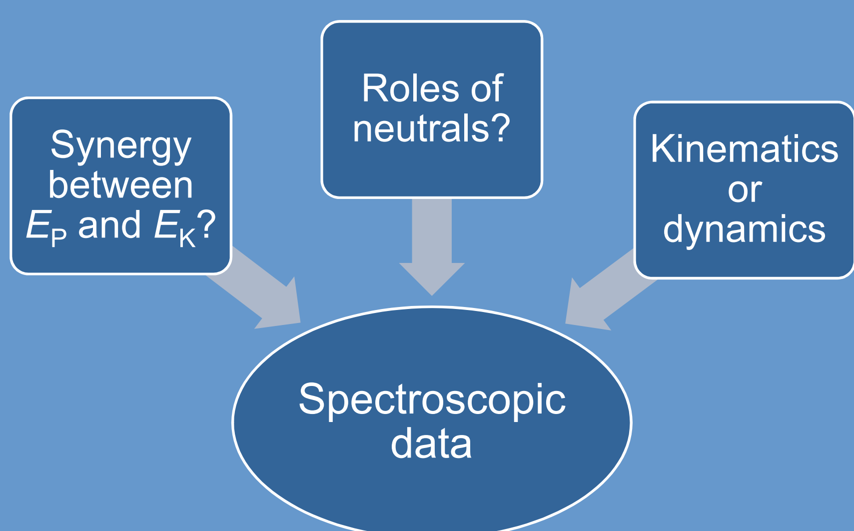
1-2. Nanostructure formation

	Mica	HOPG	LiF CaF_2	KBr	Si	TiO_2
shape	Blister[1] or Hillock[2]	Hillock[2-5] 	Hillock[7] 	Pit[8] 	Crater[9] 	Caldera[10] 
E_P–dep. of size	$V \propto E_P$	$d \propto q$ $h \propto q$	$V \propto E_P$ (E_P>14 keV)	$V \propto E_P$		
Authors	1) Shneider (1993) 2) Parks (1998)	3) Minniti (2001) 4) Hayderer (2001) 5) Nakamura (2005) 6) Tona (2007)	7) El-Said (2007)	8) Heller (2008)	9) Tona (2007)	10) Tona (2008)

1-3. Nanostructuring and Sputtering

	Contribution of **Potential Energy** E_P	Contribution of **Kinetic Energy** E_K
Nanostructuring	Volume ~ E_P (Diameter ~ q, Height ~ q) Coulomb Explosion	Independence or weak dependence of E_K Coulomb Explosion Inelastic Thermal Spike
Sputtering	Hydrogen Atoms/Molecules/Ions Yield ~ q^n $(3 \leq n \leq 5)$ Pair-wise Potential Sputtering Heavy Atoms/Molecules/Ions Yield ~ q^m $(1 \leq m \leq 2)$ Defect Mediated Potential Sputtering	Hydrogen Atoms/Molecules/Ions Negative dependence of E_K Heavy Atoms/Molecules/Ions Weak dependence of E_K Kinetically Assisted Potential Sputtering

2. Motivation



3. Objective

- To measure velocity or kinetic energy of particles participating in the collisions in order to investigate the kinematics of sputtering, desorption, and nanostructuring induced by slow multicharged ion collisions with solid surfaces.

4. Experimental Methods

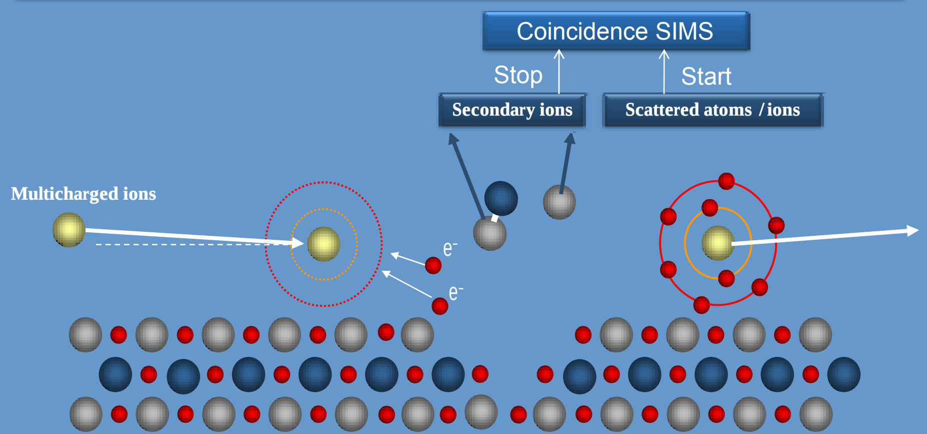
4.1 TOF-SIMS studies

- 4.1.1 3D-momentum spectroscopy of secondary ions
- 4.1.2 Simultaneous TOF-SIMS/LEIS analysis

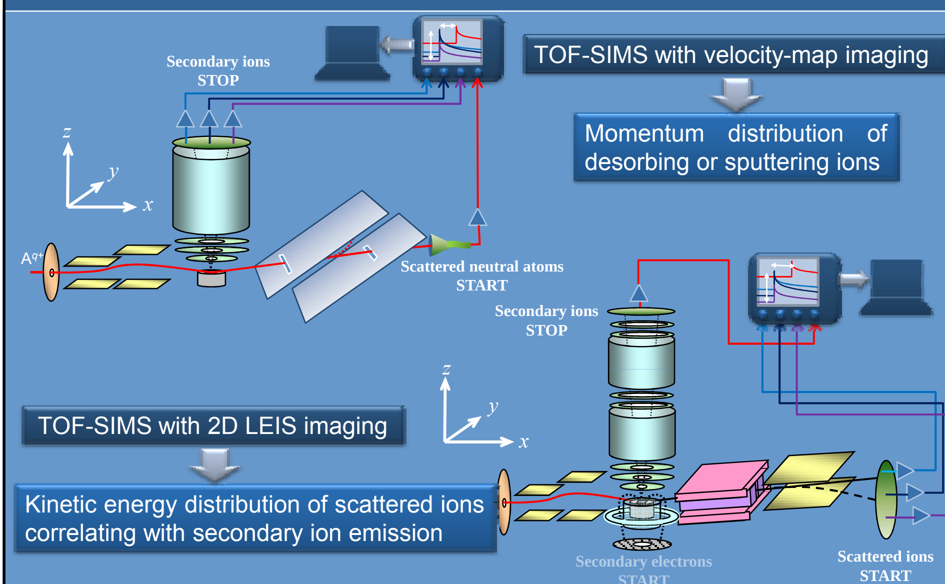
4.2 OES study

4.1. TOF-SIMS study

Secondary ions mass spectrometry (SIMS) measured in coincidence with scattered atoms or ions in off-normal incidence

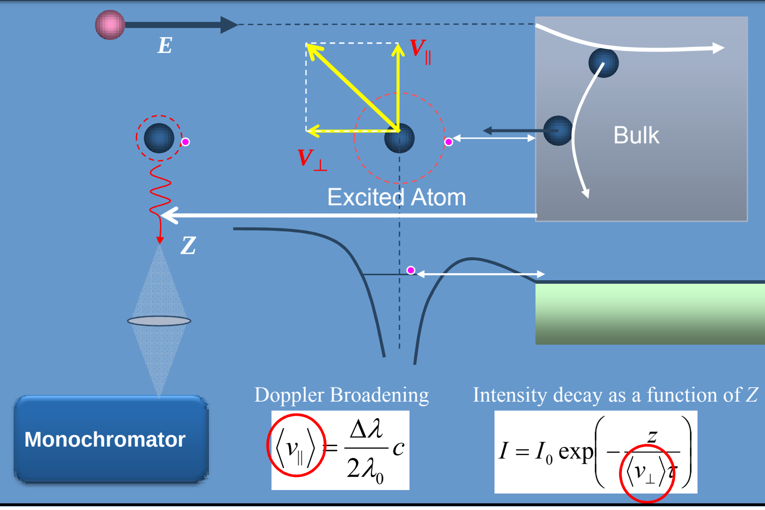


4-1. Experimental setups of SIMS



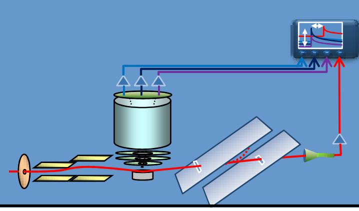
4.2. OES study

Optical emission spectroscopy (OES) of sputtered neutral atoms in normal incidence



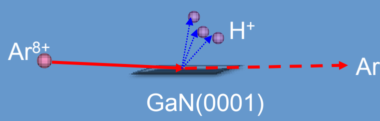
6. Results and discussion

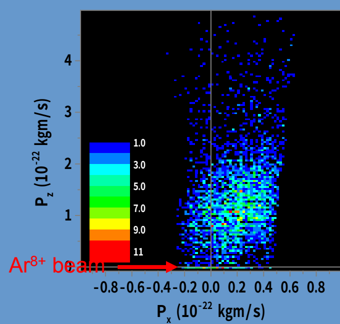
6.1. TOF-SIMS with velocity map imaging

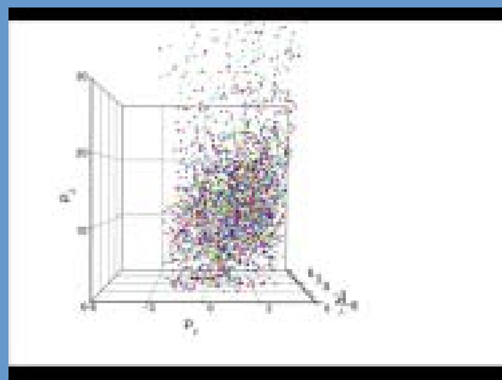


6.1.1. Proton desorption from GaN surfaces

3D-momentum image of protons emitted from a GaN(0001) surface interacting with Ar^{8+} at glancing angle (0.5°)







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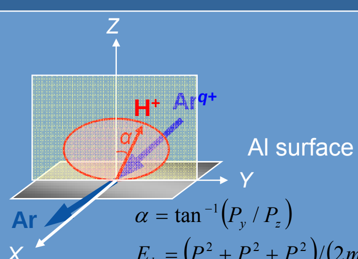
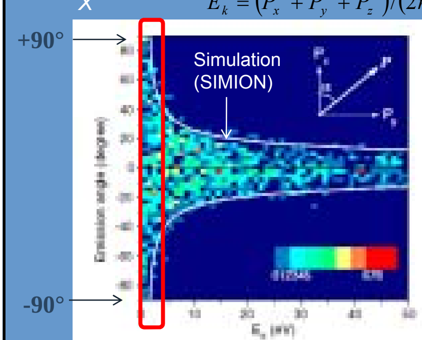
6-1-2. Angular dependence of protons

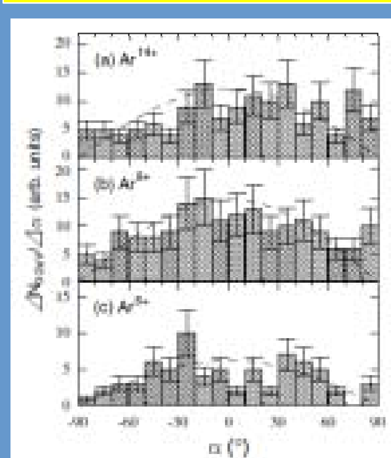


$$\alpha = \tan^{-1}(P_y / P_z)$$

$$E_k = (P_x^2 + P_y^2 + P_z^2)/(2m)$$



This analyzer can detect all protons which have the kinetic energy less than 2eV.



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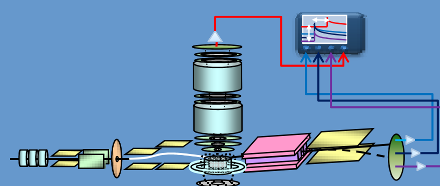
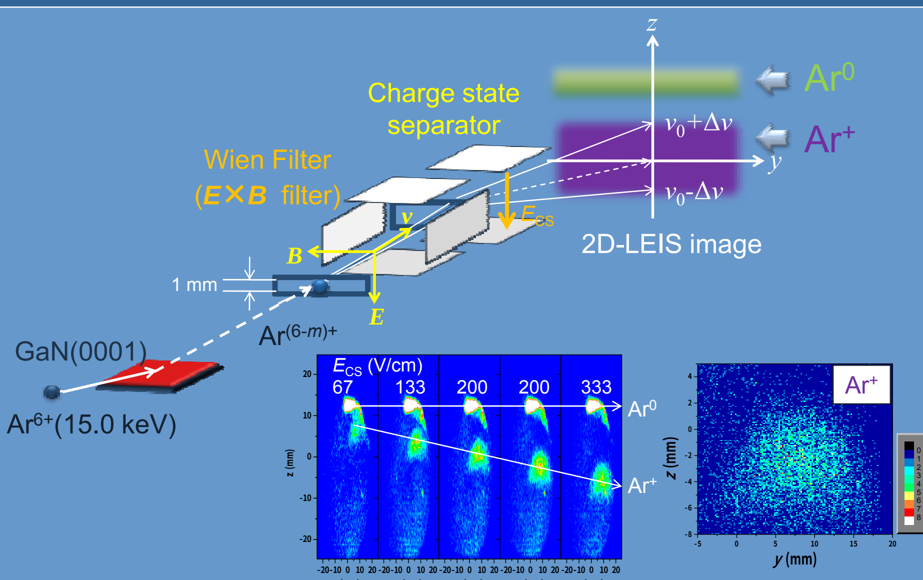
6. Results and discussion

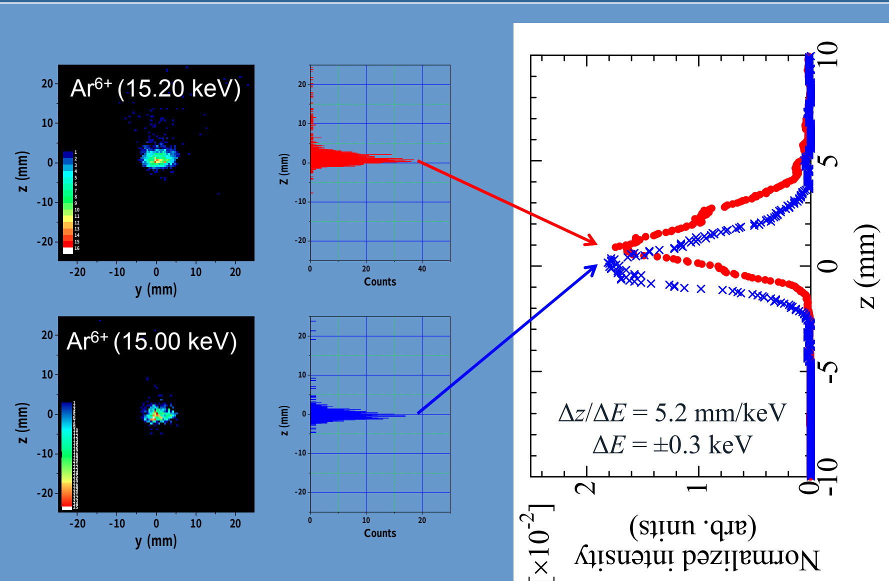
6.2. TOF-SIMS with 2D-LEIS imaging



6-2-2. Velocity dispersion with $E \times B$ filter



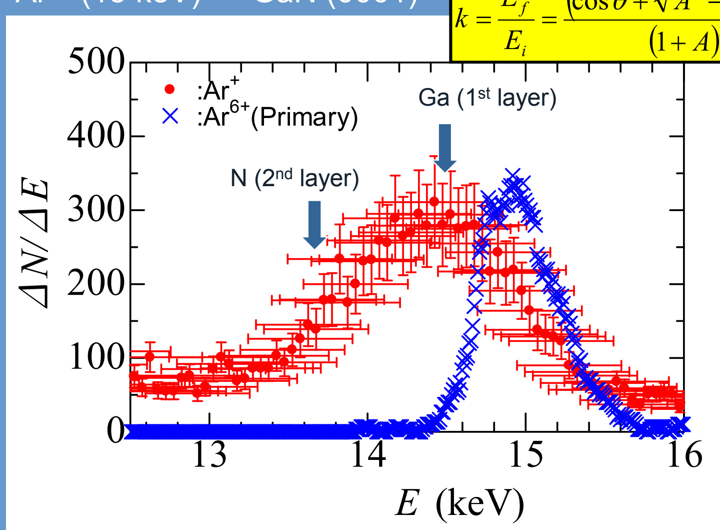
6-2-3. Energy calibration



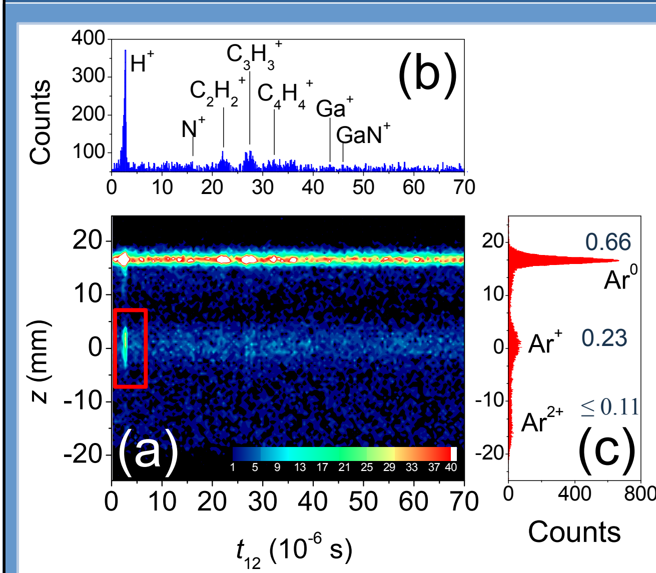
6-2-4. Result of LEIS

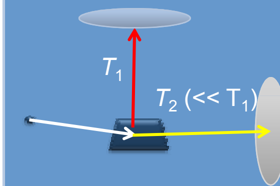
Ar^{6+} (15 keV) → GaN (0001)

$$k = \frac{E_f}{E_i} = \frac{\left(\cos\theta + \sqrt{A^2 - \sin^2\theta}\right)^2}{(1+A)^2}$$

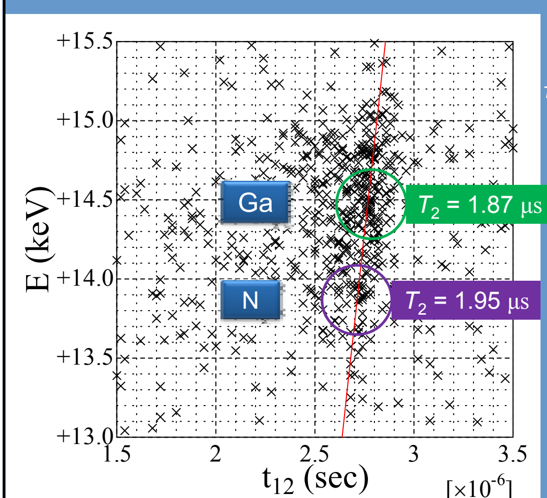


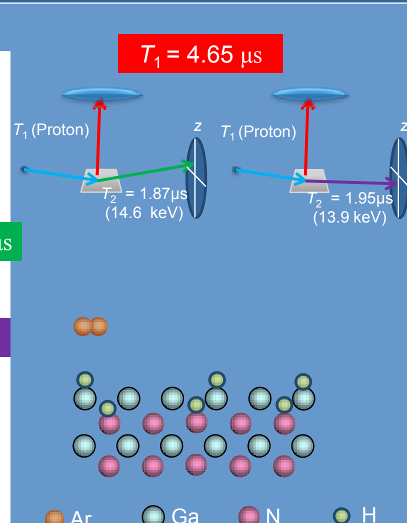
6-2-5. Result of SIMS measured in coincidence with scattered ions





Proton emission followed by elastic scattering between Ar and Ga or N

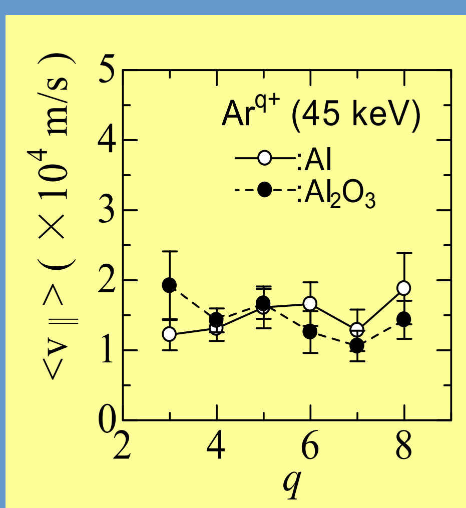




6. Results and discussion

6.3. OES

6.3.1 $<v_{||}>$ of Al^* (Previous study)



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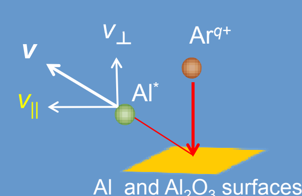
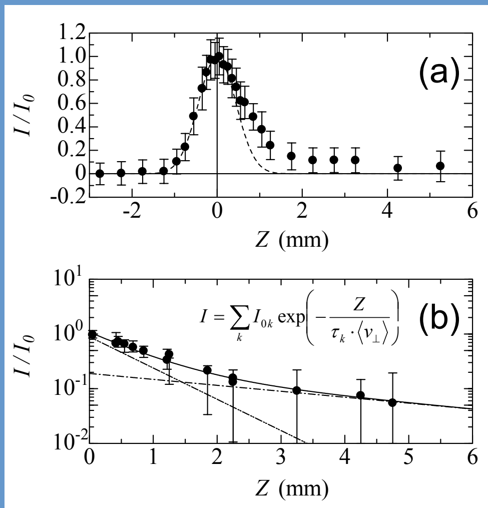


There was no significant change of $<v_{||}>$ among different charge states as well as between metal and insulator surfaces.

6-3-2. <v⊥> of Ti* (in progress)



Ti* (3d²4s4p x³G)
τ = 10.6 ns
$\langle v_\perp \rangle$ = (7±3) × 10^4 m/s

Measurement of charge-state dependence of $\langle v_\perp \rangle$ is now on going.

Summary

- TOF-SIMS coincidence measurements on scattered atoms/ions and secondary ions, and OES measurements of sputtered neutral atoms were conducted to investigate the dynamics of desorption and sputtering due to electron capture by slow multicharged ions.

- Anisotropic distributions in the proton emissions for glancing-incidence collisions were observed.
- It was found in the simultaneous TOF-SIMS and LEIS measurement that potential sputtering of protons induced by electron capture is followed by elastic scattering between projectile ions and surface atoms in the first and second layers.
- The mean velocity, parallel to the surface, of sputtered substrate atoms were almost independent on charge state of incident ions.
- The measurements of mean velocity, perpendicular to the surface, of sputtered substrate atoms are now in progress.

Acknowledgements

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