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Sandia National Laboratories

Technoscience Search: Opportunities & Challenges for Human & Artificial Intelligences

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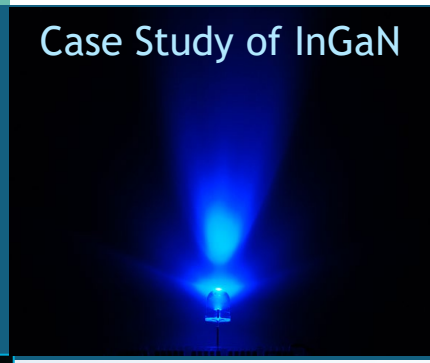
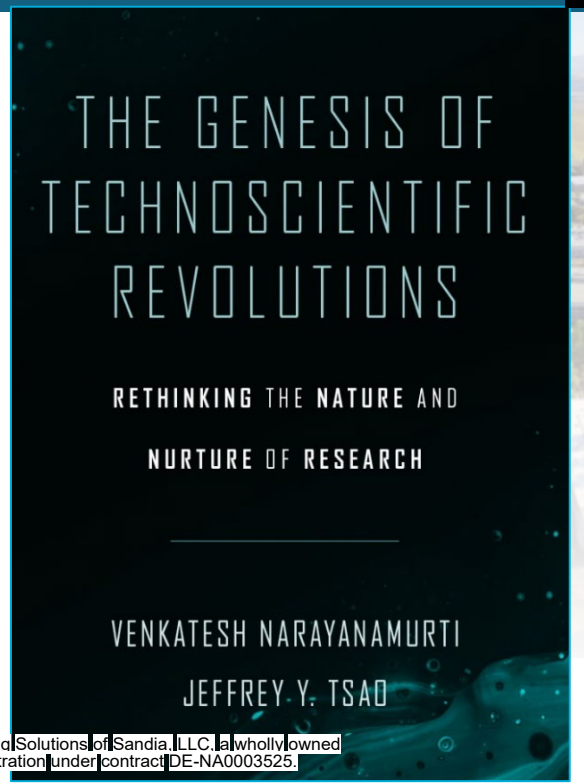


Outline

- The Technoscientific Method
- Engineering Search: Design vs Invention
- Science Search: Hypothesis vs Data Driven



Co-Design for Materials Discovery, Reliability, and Extreme Environments
November 15-17, 2022

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The Technoscientific Method (as practiced by humans)

CULTURE

HUMAN UTILITY AND LEARNING

$\dot{S}_1$: Fact-Finding

$\dot{T}_1$: Function-Finding
*for practical utility
*for learning

FACTS

$\dot{S}_1$: Fact-Finding
*observe new facts beyond existing theory (open-ended phenomena elicitation)
*observe new facts to hypothesis-test emerging theory

FUNCTIONS

$\dot{S}_3$: Generalizing

$\dot{S}_2$: Explanation-Finding

Scientific Method ($\dot{S}$) ⟷ *Neither leads, both are critical, and together they are complete* ⟷ *Engineering Method ($\dot{T}$)*

$\dot{T}_3$: Exapting

$\dot{T}_2$: Form-Finding

EXPLANATIONS

$\dot{T}_2$: Form-Finding
*use of facts and explanations to catalyze/constrain creation of new forms

FORMS

iPhone explosion from Rajkumar Remanan:
https://www.pinterest.com.au/pin/706502260271860423/

SCIENCE (*S*)

TECHNOLOGY (*T*)

Nuances

- The *S*&*T* repositories of knowledge are organized as loosely modular hierarchies of questions and answers
- Particular results of every mechanism of the technoscientific method will have various degrees of “surprise”

Engineering Search:
The Modular/Amodular and The Exploitative/Exploratory

III-V Materials & Applications Value Chain "Stack"

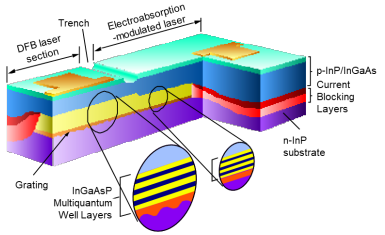
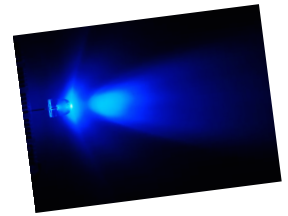
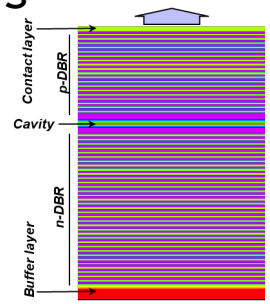
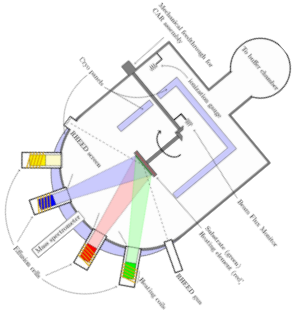
μE/oE Apps

System Architectures

Packages

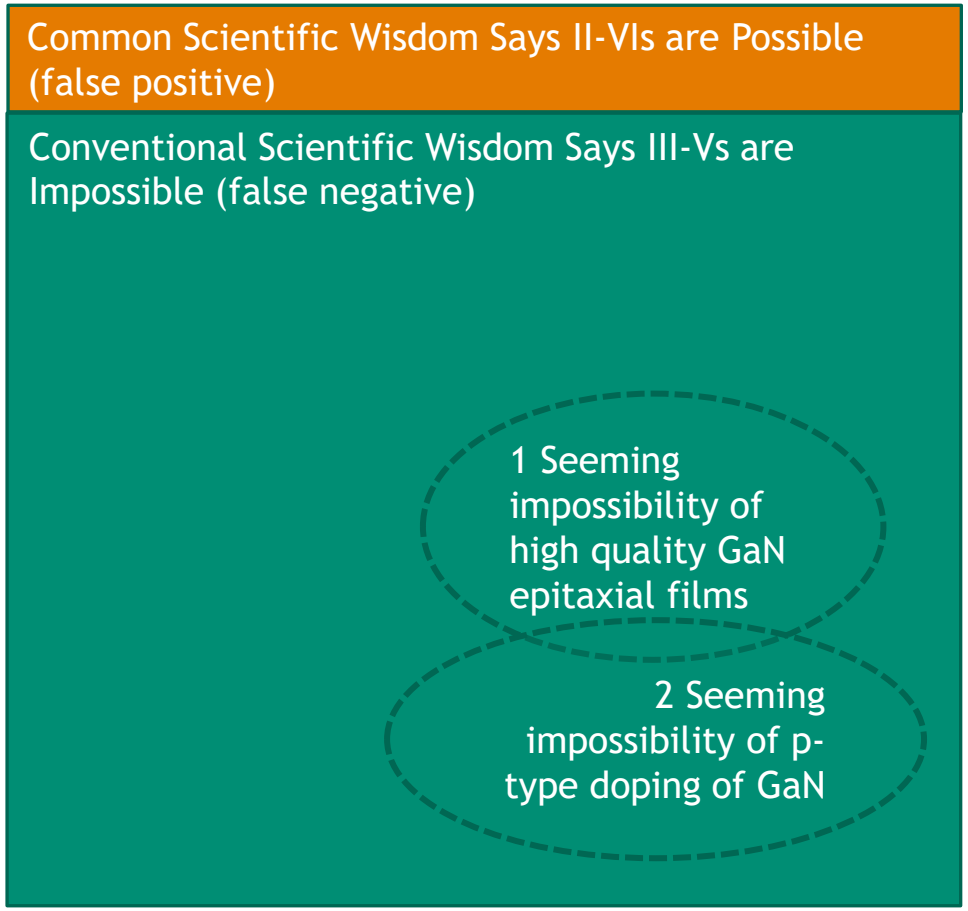
Chips

Epitaxy

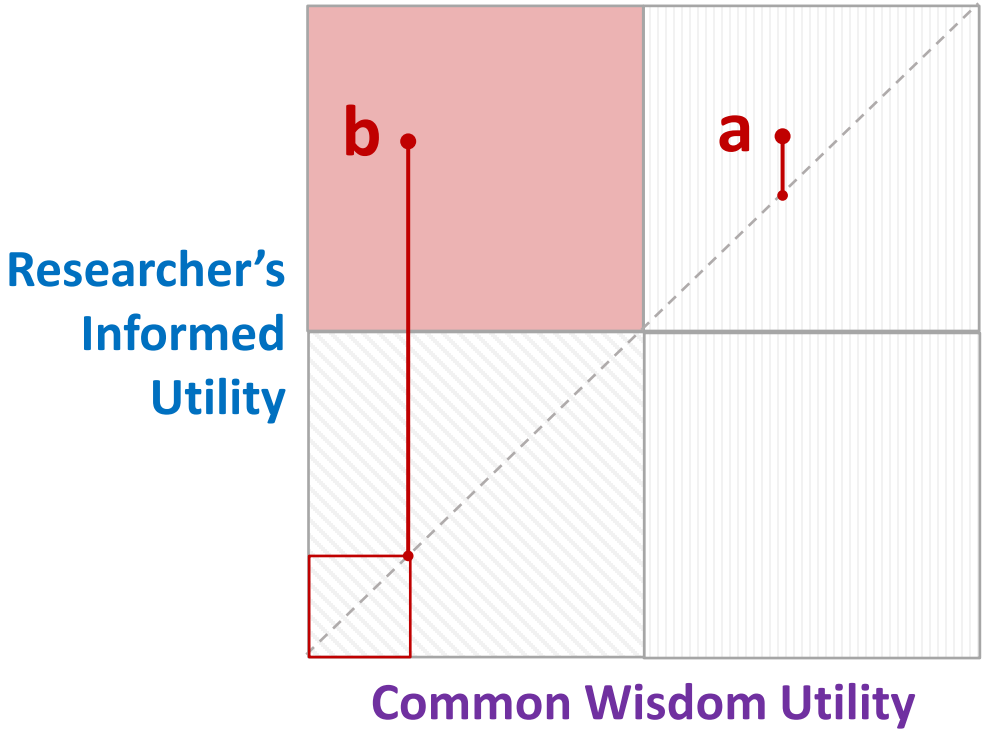
	Exploit the Known • *Enabled by "technology headroom"* • *Enhanced by science*	Explore the Unknown • *Catalyzed by "reverse salients"* • *Enhanced by contrariness*
Amodular Co-Search • *Enables fuller advantage to be taken of innovations in different levels that "break" existing protocols*	**Co-Design** 1990s: Distributed Feedback (DFB) Lasers 	**Co-Invention** 2000s: InGaN Blue LEDs 
Modular Search • *Herb Simon: modularization with protocols enables evolution of complex systems* • *Adam Smith: division of labor and knowledge specialization enables evolution of complex economies*	**Design** 1980s: Vertical-cavity surface-emitting lasers (VCSELs) 	**Invention** 1970s: Molecular Beam Epitaxy (MBE) 

Engineering Invention:
The Key Role of Surprise and Informed Contrariness

Visible Light Emitters Search Space



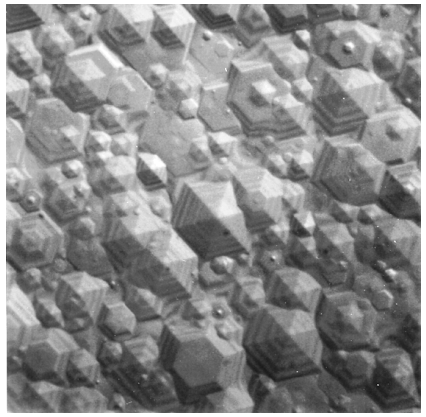
Informed Contrariness



Tsao, J. Y. (2020). *Creativity in Scientific and Engineering Research* (SAND2019-15148PE). Seminar at DOE Building Technologies Office, January 9, 2020.

Science Search: Fact & Explanation Elicitation & Finding

Akasaki & Amano:
Complex sequence of growth/annealing/growth of AlN/sapphire reduces roughness and defect density
Nakamura:
Ditto for GaN/sapphire

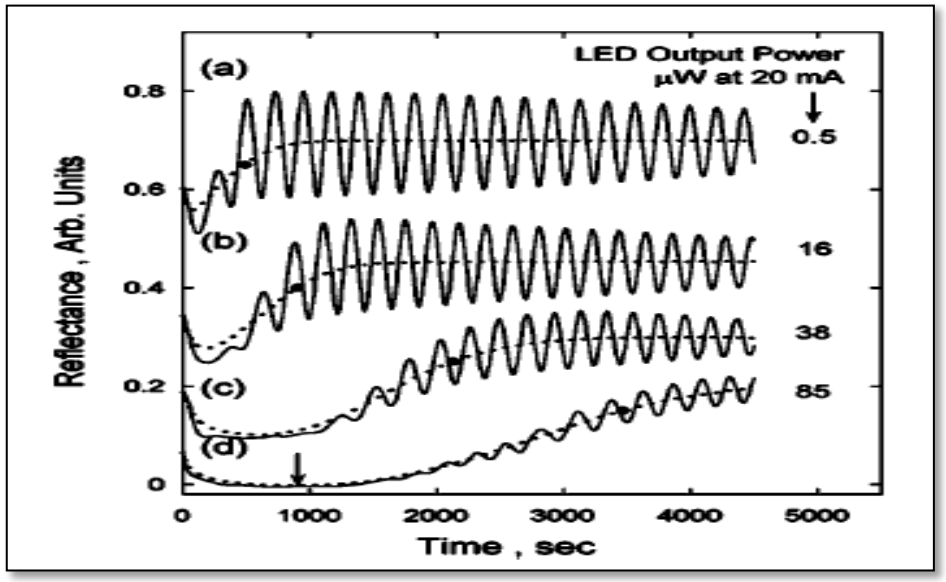


GaN/sapphire before Akasaki, Amano, Nakamura

GaN/sapphire after Akasaki, Amano, Nakamura

Han & Breiland:
Used in situ reflectance to show that severe roughness *must* precede smoothness

Koleske, Coltrin & Mitchell:
Imagined that grain ripening enables sparse nucleation followed by epitaxial lateral overgrowth



0 Scientific fact based on an engineered form that fulfills a function

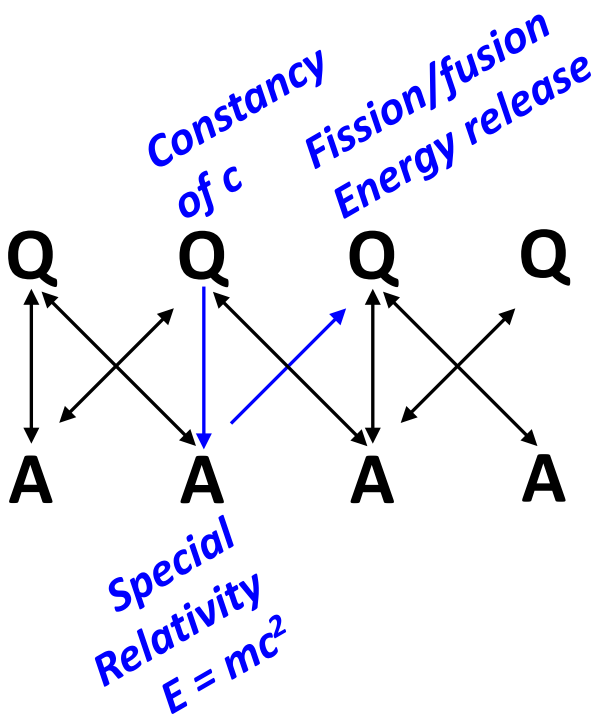
1 Imagined overarching explanation (hypothesis)

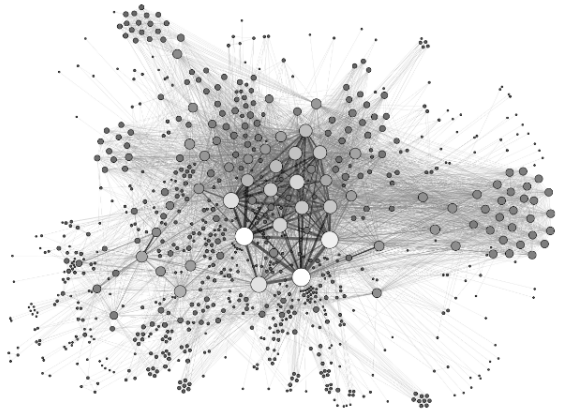
2 Auxiliary measurements to stimulate (not test) more detailed explanations (hypotheses)

3 Detailed explanations (hypotheses) and verifications

Science Discovery:
The Key Role of Analogy-Making and Generalizability

Science





Phil Anderson's
"Seamless Web of Knowledge"

PW Anderson, "Science: A 'Dappled World' or a 'Seamless Web'?" Stud. Hist. Phil. Mod. Phys. 32, 487-494 (2001).

Technology