1. Title
Smallest Nanoelectronics with Adatom Chains

2. Author
Toshishige Yamada (phone: x44333, email: yamada@nas.nasa.gov)

3. Conference
A conference talk will be given at NanoSpace-98 of NASA Johnson Space Center, November 1-6, 1998. I do not submit a proceedings paper although authors were invited to do so. Therefore, none of the slides will be published.

5. About VI author/originator verification in form1676
(1) There is no export controlled, confidential commercial information.
(2) Regarding the patent, the technical field covered here is related to ARC-14246, "Doping Method of Semiconducting Atomic Chains." This is a talk only, without a proceedings paper (abstract was submitted last spring, and form 1676 was filed and approved at that time), and ARC-14246 covers the content. The talk is focused on the general aspect of atomic chain electronics that I have been studying for last three years. Results have been published before, but are being rederived here using a *new* physical/mathematical picture/model, which deepens the physical understanding. The content is protected from a patent point of view.

6. Slides
See the attached copy.

IN:T27A-1 September 24, 1998

RTOP # 519-40-12 Description

RTOP # 519-40-12 authorizes Code IN work by the Application Analysis and Tools (AAT) Group in partial fulfillment of Information Technology (IT) program objectives documented in the IT Program Statement, cf. Sec. 2.1.1.1. Technology dissemination is authorized under guidelines set forth in Sec. 5.0 "Technology Transfer/Sensitive Data Control". The IT program is currently administered by acting program manager Eugene Tu (ext. 4-4486).

The document entitled **"Smallest Nanoelectronics with Adatom Chains"**, written by **Toshishige Yamada**, conforms to Sec. 5.0 guidelines, and contains no material under direct or indirect control of the U.S. Commerce Department.

Smallest Nanoelectronics with Atomic Chain

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3. Lateral coherent coupling

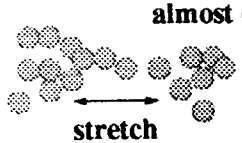
Si(111)2x1 dangling bond chain:
Stroscio, Feenstra, & Fein, JVST A 5, 838 ('87)

lateral coupling

4. Conductance quantization

Muller, van Ruitenbeek, & de Jong, PRL 69, 140 ('92)

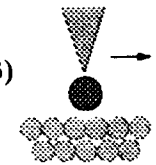
almost disconnected atomic wire



$\sigma \sim 2e^2/h$

Rapid progress in STM experiment

1. Atom manipulation with STM

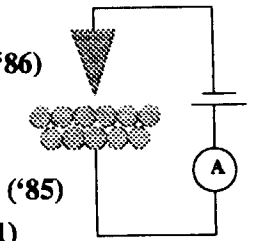


Fe on Cu:
Crommie, Lutz, & Eigler, Science 262, 218 ('93)

Si on Si:
Avouris & Lyo, Science 253, 173 ('91)

H on Si:
Shen, Wang, Abeln, Tucker, Lyding, Avouris, & Walkup, Science 268, 1590 ('95)

2. Vertical I-V spectroscopy with STM



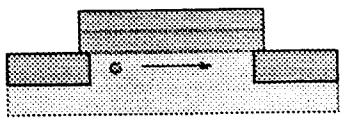
Si(111)2x1:
Stroscio, Feenstra, & Fein, PRL 57, 2579 ('86)

Si(111)7x7:
Becker, Golovchenko, Hamann, & Swartentruber, PRL 55, 2032 ('85)

Kubby, Wang, & Green, PRB 43, 9346 ('91)

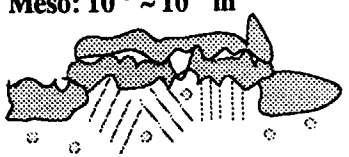
Smallest electronics with presice structures

Macro: $> 10^{-6}$ m



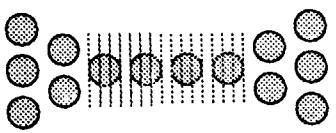
Uniform
Predictable
Controllable

Meso: $10^{-8} \sim 10^{-7}$ m



Nonuniform
Unpredictable
Uncontrollable

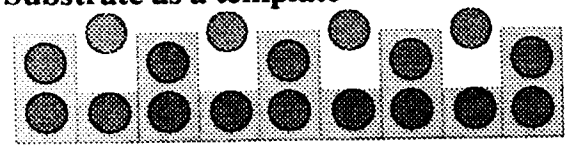
Atomic: $< 10^{-9}$ m



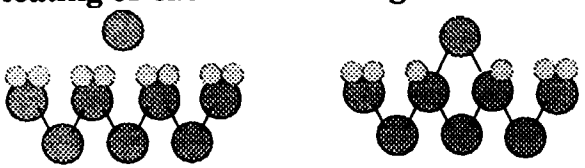
Uniform
Precise, accurate
Designable

Precise structures

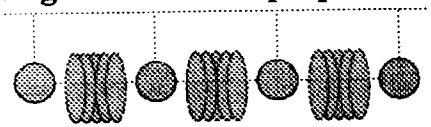
Substrate as a template

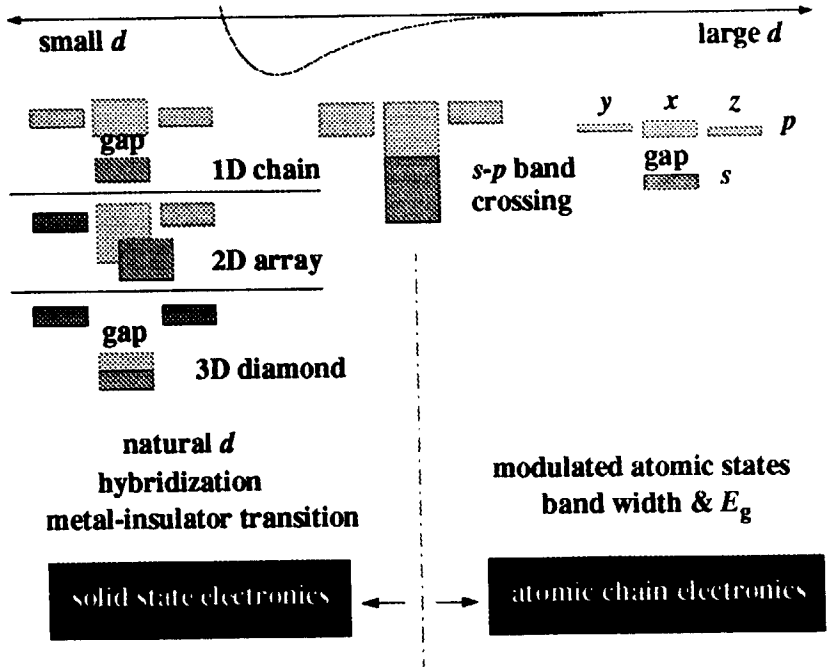


Floating or chemical bonding



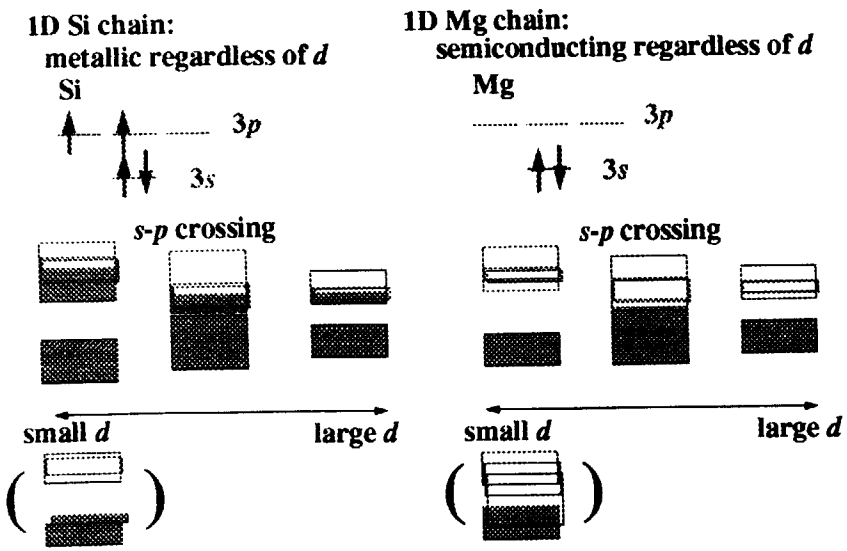
Spacing d = electronic properties





Electronic properties with tight-binding theory

Yamada, JVST B 14, 1243 ('96); A 15, 1280 ('97); B 15, 1019 ('97)

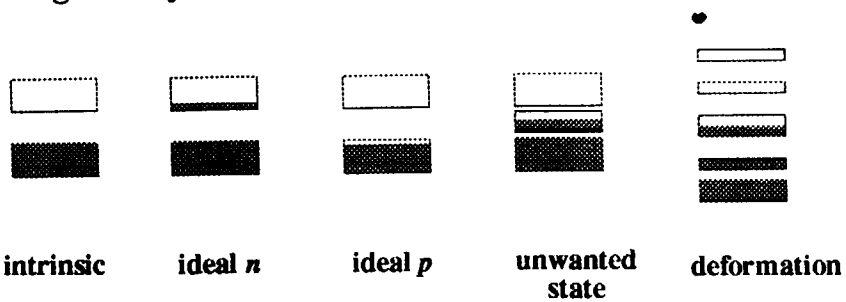


Electronics:

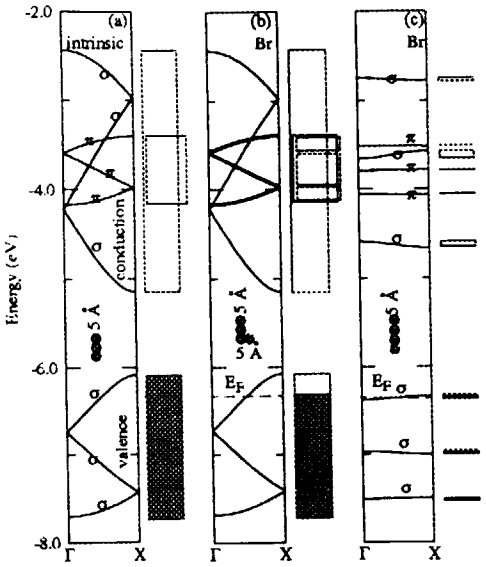
want p- and n-semiconductors

Doping scheme:

dopant?
geometry?



Atomic modulation doping - least band deformation



Yamada, JVST A 16, 1403 ('98)

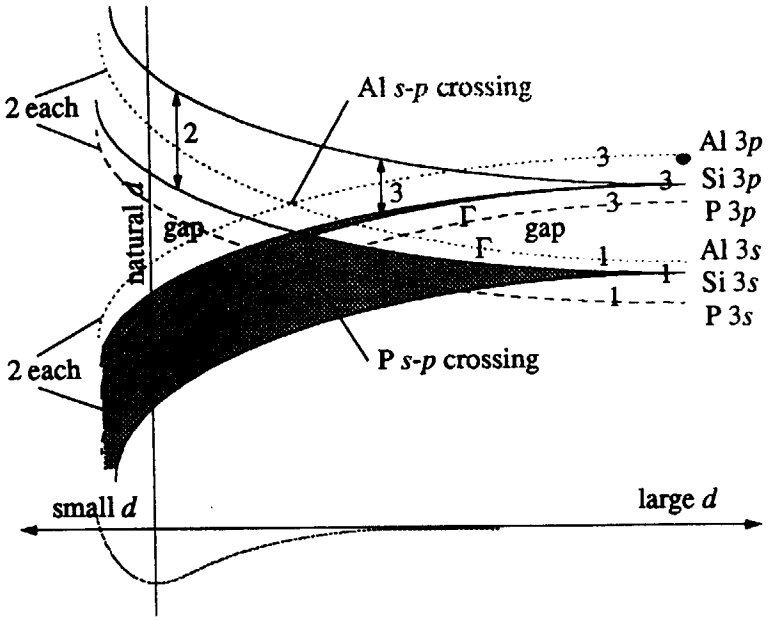
donor: group I (not III)
acceptor: group VII (not I)

(a) intrinsic semiconducting Mg

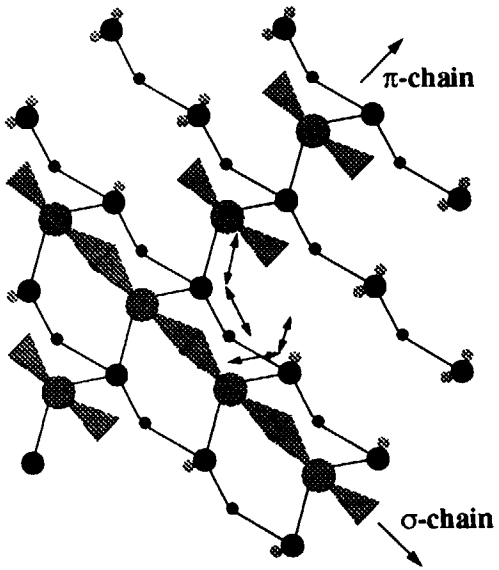
(b) modulation doped chain

(c) directly doped chain

3D Si band with acceptor Al and donor P



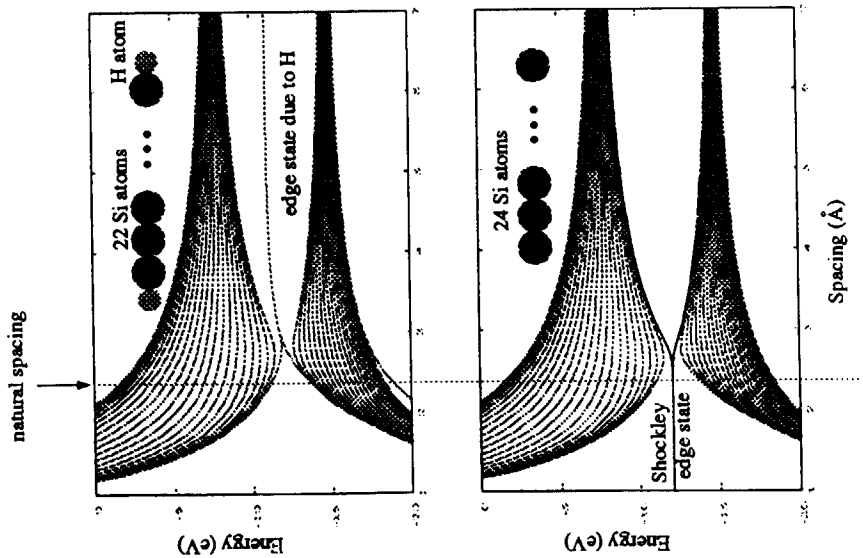
Substrate effects



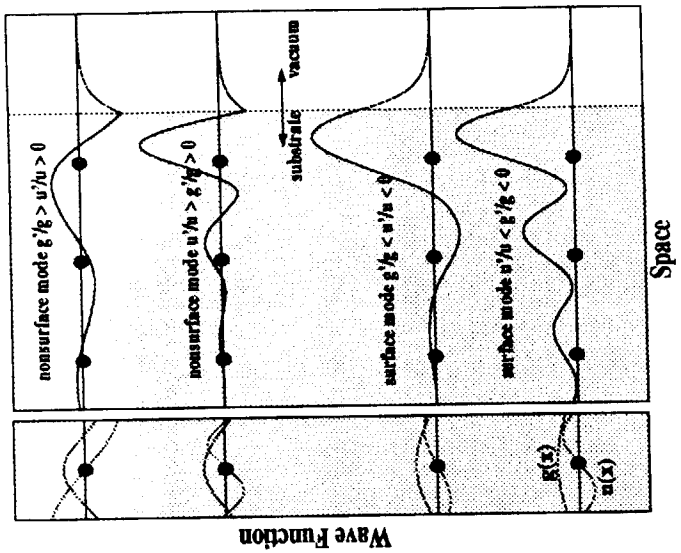
Adatom chain bound to unreconstructed Si (100) surface with unsed dangling bonds saturated with hydrogen

- group IV adatom
- hydrogen
- first layer silicon
- second layer silicon

1. Reduce orbitals available for chain
2. Unintentional doping



Conditions for Shockley surface mode

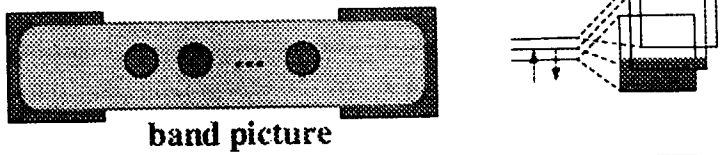


At contact:

Yamada, JVST A 15, 1280 ('97)

Frequent exchange (Ohmic contact)

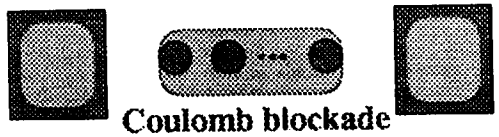
extended, large *C*



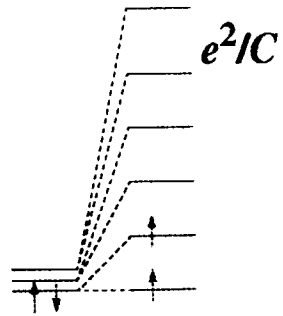
band picture

Infrequent exchange

localized, small *C*



Coulomb blockade



Summary

Precise adatom structures on a regulated surface as a template - no uncertainty

So far

Mg chain: semiconducting
Doping method:
Periodic, beside the chain
Donors group I, acceptors group VII

Future

Substrate effects
Ohmic contact
Transport through junctions
Towards devices with gain