THEN AND NOW

JRCAT

An Innovative Research Organization and Its Present Status

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Atom Technology Project

The Atom Technology Project was started in the 1992 fiscal year as one of the projects managed by a quasi-government organization, the New Energy and Industrial Technology Development Organization (NEDO), and sponsored by the Ministry of International Trade and Industry (MITI), with a planned total budget of 25 billion yen for 10 years. The Project is a basic research program aimed at the establishment of technologies to identify and manipulate individual atoms and molecules, and expected to be positioned as a generic technology to underlie various industrial fields, such as new materials, electronics and biotechnology.

In Phase I, spanning 6 years to fiscal year (FY) 1997, R&D efforts were concentrated on elementary and supporting technologies, while in Phase II, beginning in FY 1998, the project has been oriented towards more specific targets, the study areas being more focused.

Let us look back at the situation around the beginning of the 1990s, when Japanese industries were enjoying an extended business boom owing to the persistence of the bubble economy. Following extensive investment in basic research and the recruitment of competent R&D personnel during the previous decade, industry was becoming confident its ability to create and develop technologies using its own resources. It was even claimed that national research institutes were no longer necessary, except in the fields of the environment and energy, thanks to the vitality of the private sector. On the other hand, foreign countries were increasingly criticizing application development projects in Japan, through the joint efforts of government and the private sector, because of the perceived Japanese "free ride" on Western-generated basic technologies.

In these circumstances, MITI decided to reorganize the national research institutes and shift R & D work towards basic research in order to meet the requirements of the new age. The Atom Technology Project was designed in response to the various demands, as a basic R&D program involving intense joint efforts on the part of the key three sectors: industry, government and academia; and, to implement these new initiatives, the National Institute for Advanced Interdisciplinary Research (NAIR) and the Joint Research Center for Atom Technology (JRCAT) were founded.

Organization of JRCAT

The Atom Technology Project involves a number of innovations. All the R&D work is carried out centrally by scientists of different affiliations and backgrounds gathered together in NAIR. Researchers are invited from industry, national laboratories and universities to undertake tripartite joint research. A number of legal barriers had to be overcome in order to make it possible for scientists from the industrial and academic sectors to work in NAIR, a national institute.

The research organization for realizing the tripartite joint research is illustrated sche-

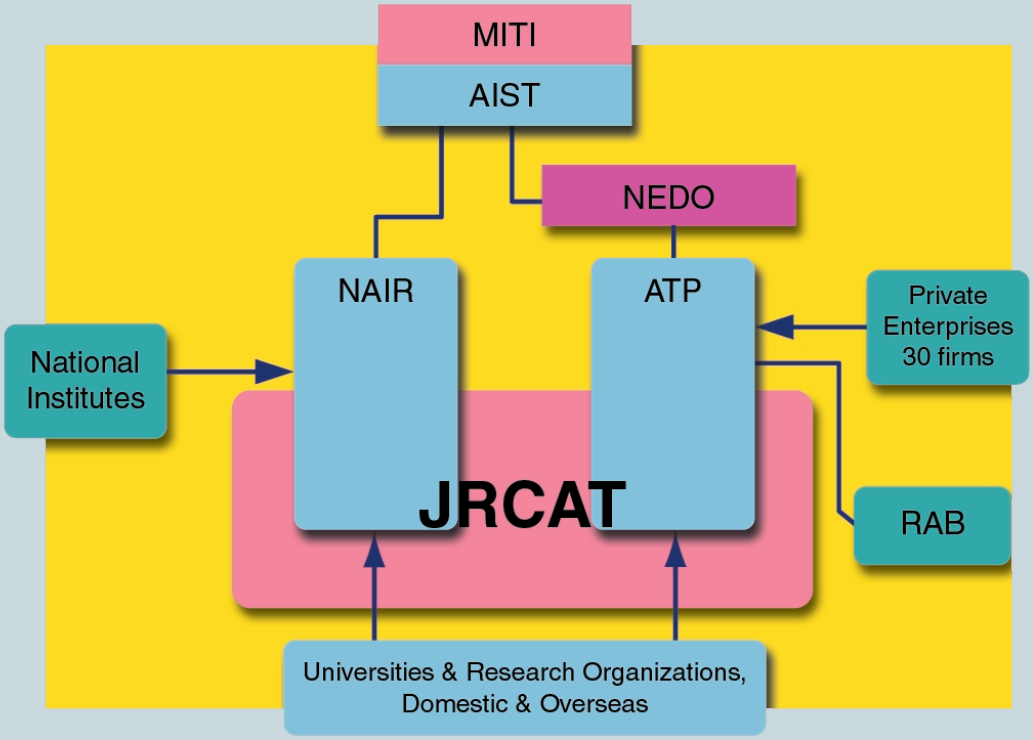

Figure 1.
Organization chart representing JRCAT (Joint Research Center for Atom technology) and its related organizations; AIST (Agency of Industrial Science & Technology); NEDO (New Energy & Industrial Technology Development Organization); NAIR (National Institute for Advanced Interdisciplinary Research); ATP (Angstrom Technology Partnership); RAB (Research Association for Biotechnology)

matically in Figure 1. The core of the joint research organization consists of NAIR and a technological research consortium, the Angstrom Technology Partnership (ATP). Scientists from private enterprises are loaned to the ATP; those from national institutes under MITI or other ministries are concurrently appointed to NAIR; and universities are either appointed to NAIR or to ATP. In order to guarantee equal partnership among the researchers, a joint research contract was signed by NAIR and ATP, and all the researchers engaged in research activity work in the laboratories of NAIR under a unified R&D entity, namely the Joint Research Center for Atom Technology (JRCAT). This approach has the following merits: (1) the most appropriate scientists can be selected from any sector without being hindered by barriers of affiliation, and (2) quick and flexible decision-making is facilitated by the single management of a project leader endowed with plenary power.

In short, JRCAT is an ambitious, experimental organization aimed at eliminating two major drawbacks inherent in more conventional organizations in Japan: those of "vertical division" and "delayed decision-making".

As of June 1999, JRCAT includes 10 R&D groups (8 experimental and 2 theoretical) and 104 research scientists originating from the following institutes: 25 from ATP (with 30 member firms), 25 from national research institutes, 12 from universities (3 professors and 9 students) and 42 postdoctoral researchers (including 20 foreigners). The unified budget management enables JRCAT to operate its own postdoctoral invitation program, called the JRCAT fellowship.

Focused Fields and Research Groups

The four focused Phase II fields and the research groups in charge of the work at JRCAT are described below.

Field 1 concerns "Identification and Manipulation of Atoms and Molecules". The Tokumoto group and the Ishikawa group cover this area, which deals with the imaging and identification of atoms and self-assembled monolayers, and of DNA molecules, respectively.

Field 2 investigates "Formation and Control of Nanostructures at Surfaces and Interfaces". Four groups, namely those of Ichikawa, Ozeki, Kanayama and Yamasaki, are dedicated to this field. The aim is to establish technologies for the preparation, measurement and characterization of 10-nm sized nanostructures.

Field 3, "Spin Electronics", is a top priority area based on the results of Phase I studies. Two groups are engaged in this area: the Tokura group is attempting to clarify the background physics underlying the magnetic and electronic phase transitions in perovskite-type transition metal oxides and to explore for potential applications, while the Tamura group pursues research into spin-polarized scanning tunnelling microscopy

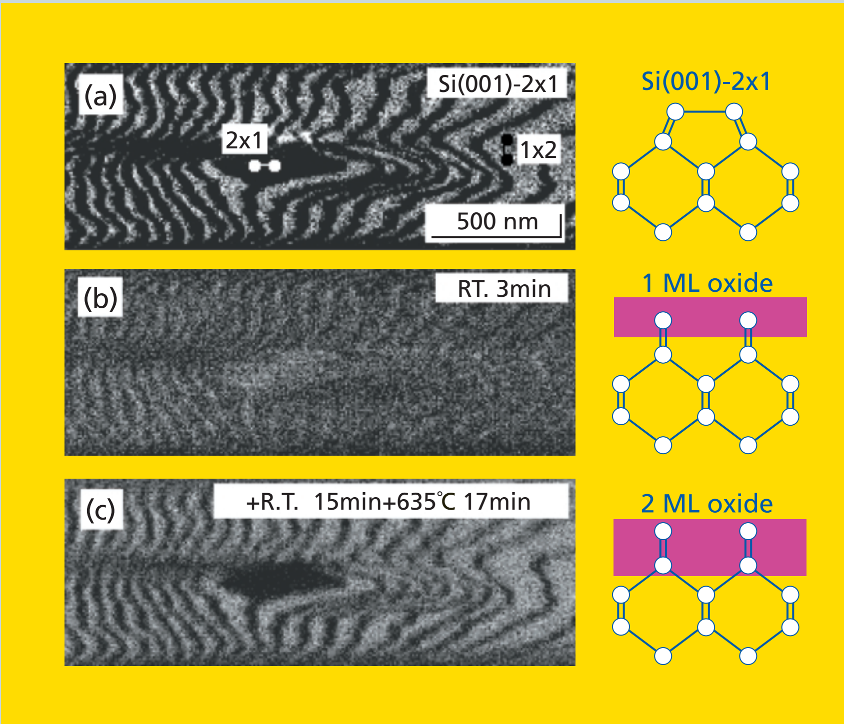

Figure 2.
Scanning reflection electron microscope (SREM) images of the Si(001) surfaces before and after oxidation: (a) initial Si(001)-(2x1) surface; (b) first contrast reversal corresponding to oxidation of uppermost dangling bonds and the first subsurface layer; and (c) corresponding to oxidation of second subsurface layer (Watanabe *et al.*, Phys. Rev. Lett. **80**, 345 (1998)).

(STM) and scanning electron microscopy (SEM).

Field 4, "Theoretical Analysis of Dynamic Processes of Atoms and Molecules", is studied by the Terakura and Uda groups, which carry out joint research with experimental groups based on the calculation of electronic states from first principles.

In summary, the Atom Technology Project covers a broad area of nanotechnology, embracing the identification of atoms and molecules, their manipulation and spin control, thus providing not only a firm foundation for nanotechnology but also creating a new paradigm for materials science.

R&D Activities

Some of the results achieved by the Project in the five years of Phase I since substantial start R&D work was started in FY 1993 are summarized in Table 1. In particular, the number of scientific papers arising from JRCAT (original papers only, with conference proceedings excluded), the number of invited lectures in international conferences and the number of patents filed, are listed for different fiscal years. These results were presented in 15 or so symposia and workshops, both large and small in scale, held by JRCAT. Of these meetings, 11 were international. That JRCAT could hold so many international meetings was due to the NAIR Foreign Researcher Invitation Program, which allows the invitation of 20 or so researchers per year from overseas to attend workshops.

For the first 6 years of Phase I, the materials of interest have included semiconductors (Si, II-VI, III-V, amorphous), organic substances including biomolecules, magnetic thin films and transition metal oxides, while the underlying technologies and phenomena range from atomic manipulation, not only on the solid surface but also in three-dimensional free space, to phase transitions in strongly correlated electron systems. Some of the work was carried out in close collaboration with theory groups: two such examples are outlined below.

Watanabe *et al.* and Fujita *et al.* of the JRCAT Ichikawa group have intensively studied layer-by-layer the oxidation of Si(111) and Si(001) surfaces in an ultrahigh vacuum system using scanning reflection electron microscopy (SREM) and x-ray photoelectron spectroscopy. Through detailed analyses of SREM images in combination with XPS data they have demonstrated that the periodic reversal of the terrace contrast in the SREM images (see Fig.2) corresponds crucially to layer-by-layer oxidation of the Si(001) surface. They have also found indications that, at low temperatures below 200°C, oxidation of the first subsurface layer (i.e., back-bond oxidation) and oxygen chemisorption onto the top layer is barrierless, whereas second-layer oxidation proceeds as a thermally-activated process. For the back-bond oxidation of the Si(001) surface, Kato *et al*. of the Uda group of JRCAT have provided complementary theoretical confirmation based on

(a)	Publications	FY93	FY94	FY95	FY96	FY97
	Nature	-	1	2	1	2
	Scieince	-	-	1	2	-
	PRL	-	-	11	6	10
	APL	-	2	7	15	22
	PRB	1	5	7	16	18
	JJAP	3	5	9	4	6
	Total	24	28	93	120	103
(b)	Invited Talks	3	10	25	44	74
(c)	Patents Filed	-	10 (0)	26 (3)	22 (1)	26 (8)

PRL : Phys. Rev. Lett., APL : Appl. Phys. Lett., PRB : Phys. Rev. B, JJAP : Jpn J. Appl. Phys.

Table 1.
Research output from JRCAT: (a) publications in scientific journals (proceedings papers not included), (b) invited talks at international conferences, (c) patents filed; numbers in parentheses represent overseas patents.

ab initio calculations.

The Tokura group aims to explore new electronic materials and the related physics for the development of atom technology. In fact, Tokura and his coworkers have demonstrated over the past five years that insulator-metal transitions, with regard to magnetic order in perovskite-type manganese oxides, can be induced by a magnetic field, an electric field, or light irradiation. Quite recently, Kawasaki *et al*. of the same group discovered chain-type antiferromagnetic insulator, ferromagnetic metal, and layer-type antiferromagnetic metal phases in epitaxial $La_{1-x}Sr_xMnO_3$ thin films grown on perovskite substrates with different lattice parameters. This strain-induced orbital-ordering transition has been studied by Fang and Terakura of JRCAT as a function of the lattice-constant ratio (*c/a*) and doping (x), from the standpoint of calculations from first-principles; the calculations agree well with the experimental results.

In this way, experiment and theory groups are collaborating effectively within the centralized joint research system of JRCAT.

Concluding Remarks

The Phase I studies of the Atom Technology Project were completed within 6 years, and we are now in the second year of Phase II. In March 1997, a report on the pre-intermediate assessment of the R&D work completed in the first 5 years of the Atom Technology Project was issued by an outside review committee of external specialists. The project was evaluated with respect to the planning, direction, and management, as well as scientific and technological achievements. In particular, the NAIR-JRCAT concept was seen as a pioneering attempt to promote industrial-governmental-academic research cooperation. The intensive joint research in which academic, government and industrial scientists are engaged, greatly encouraged face-to-face contact, is producing a free and open atmosphere rarely seen in Japan.

It must be admitted, though, that where there is light there is shade, so our organization is not yet perfect. Still, it may be regarded as an important a managerial experiment in preparation for the revolutionary changes expected to occur in the beginning of the next century, when national institutes will be turned into independent agencies. The participants in this experiment therefore have a responsibility for conveying the story of JRCAT to the coming generation so that the results may be utilized effectively in the future.

Reference

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