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# Recent Progress and Subjects of Plasma Applications
# 最近のプラズマ応用の進展と課題

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Plasma has been widely used in various scientific and industrial fields for more than 30 years. In recent years, control of plasma processing for materials synthesis has become difficult because of technological problems and practical needs: low-temperature, annealing-free, damage-free, high-rate & low-cost, vacuum-free, green process, maintenance-free processes et al. From the scientific point of view, it is required to investigate on plasma induced subsurface just under the surface of depositing or etching layers.

## 1. Introduction

Application of the forth state of matter: plasma has been widely used in the various industries. In recent years, people can usually hear the word “Plasma” such as Plasma TV, Plasma cleaning, Plasma engine etc. Thus, plasma technologies are useful in the various industries such as Energy, Electronics, New Materials, Environment, Biology and Nanotechnology. However, we must find that it is not a “Plasma Industry” in spite of their principal or indispensable role for these industries.

Here, we will discuss about newly constructing plasma induced subsurface science for more intelligent plasma process in the 21st Century.

## 2. Plasma Application Technology

Figure 1 shows the tree of plasma application based on plasma science. In addition to the conventional fields such as Light Sources, Energy and Semiconductor, new applications of plasma in the fields such as Biology, Nanotechnology and Environmental are increased.

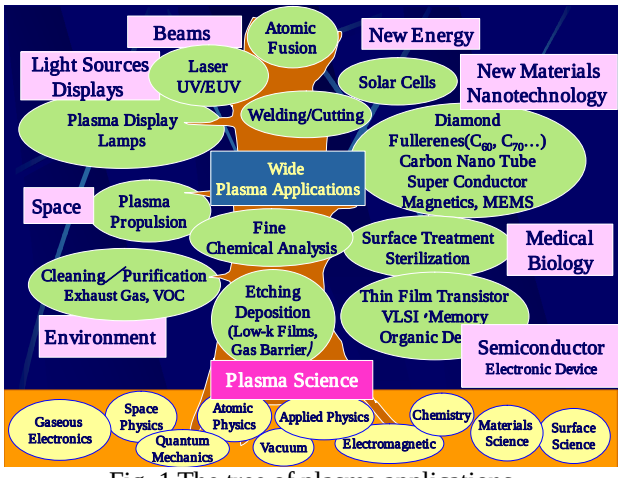

Fig. 1 The tree of plasma applications

We must note that it takes around 15 years or more to put a research idea to practical use, for example, Plasma Display Panel.

## 3. Subjects for Plasma Processing

Figure 2 shows a lot of research subjects for plasma deposition such as PACVD and Plasma PVD. As the technological problems and/or practical needs, it should be nominated that low-temperature, annealing-free, damage-free, high-rate & low-cost, vacuum-free, green process without environmental damage, maintenance-free processes. Especially, an annealing-free low-temperature deposition process is strongly required for use of flexible substrates.

For more precise control of desirable film quality, we should collect the real information about “subsurface” under depositing or etching layer on the substrate. Subsurface including the plasma-wall (solid, liquid) interactions under a processing is the most important subject.

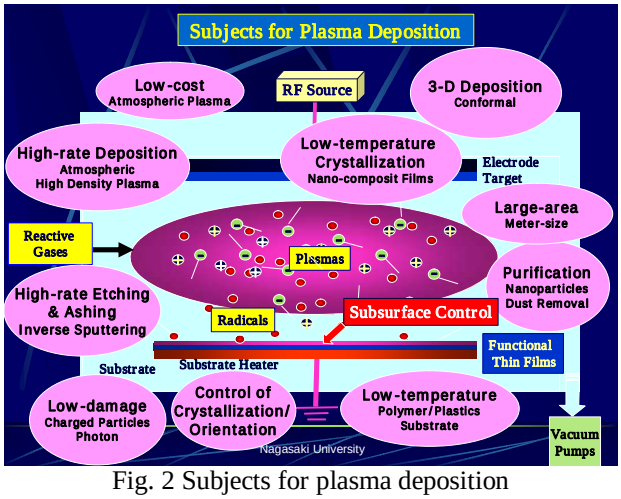

Fig. 2 Subjects for plasma deposition

## 4. Plasma Induced Subsurface Science

### 4.1 Subsurface Structure

"Subsurface" is just depositing or etching layers with several nm ~ several 10nm thicknesses, as shown in Fig. 3. This figure shows the subsurface reaction during beam etching on Si substrate by Molecular Dynamics (MD) Simulation by S. Hamaguchi. The structure near surface of etching layer is also shown in this figure. There are two parts of gas-phase and solid phase subsurface regions. Plasma induced subsurface seems to be liquid-phase before solidification.

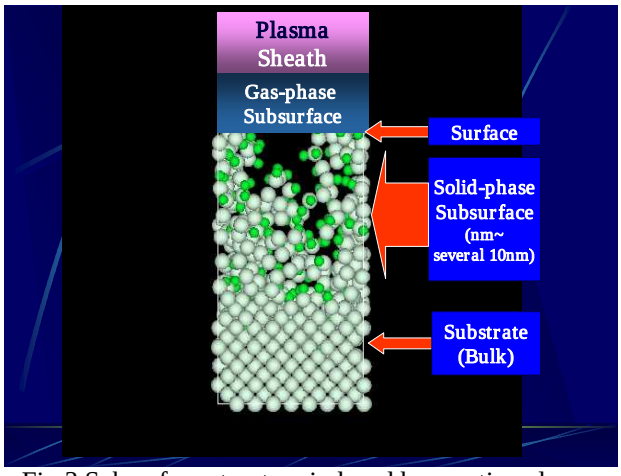


Fig.3 Subsurface structure induced by reactive plasma

### 4.2 Plasma Induced Subsurface Science

To control subsurface reactions in reactive plasmas, we should firstly measure subsurface parameters such as the temperature, particle flux and energy, photon flux, transport ratio and reaction time etc. Infrared absorption spectroscopy (IRAS) in multi internal reflection is one of useful method to diagnose the solid-phase subsurface parameters.

Computer simulation such as MD is useful tool to design the model of subsurface reaction.

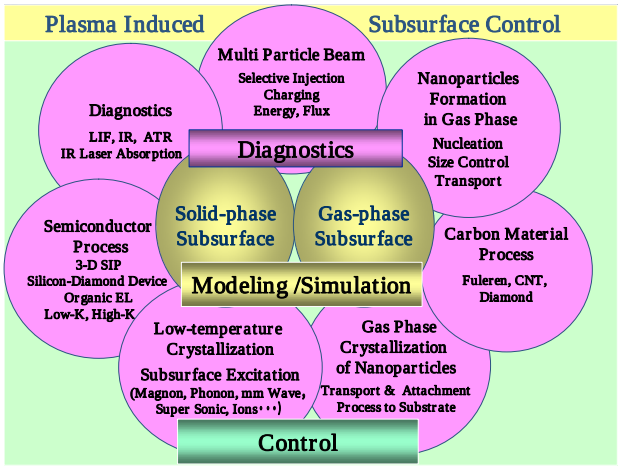


Fig. 4 Approach to plasma induced subsurface science

Figure 4 shows the example of research subjects to approach "Plasma Induced Subsurface Science". The author is interest in low temperature crystallization by direct excitation of solid-phase subsurface by magnon, phonon, mm-wave and supersonic wave etc.

## 5. Conclusion

Recent subjects of plasma application, especially plasma processing, was discussed. Plasma induced subsurface is most important reactive layer under construction of thin film deposition and etching.

To precise control of film quality, it is expected the understanding of subsurface induced by reactive plasmas.

Acknowledgments

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