Contribution to Development of Next-Generation CMOS Products

Development of technology for evaluating ultrathin-film laminated structures

Research method

X-ray diffraction/scattering

Beamline used at SPring-8: Sunbeam ID (BL16XU)

Achievements

- Realization of high-precision evaluation of film thickness, flatness, and density distribution by developing a technology for measuring characteristics such as the thickness of ultrathin films with a sensitivity 5 orders higher than that of conventional technologies
- Establishment of process conditions for manufacturing next-generation **CMOS*** products with high reliability
- Tremendous contribution of this evaluation method to the development of CMOS products produced on an approximately 2 trillion yen scale in Japan.

R&D facility: Fujitsu Laboratories, Ltd.

***CMOS** stands for complementary metal oxide semiconductor, a type of semiconductor structure; the abbreviation CMOS is commonly used. Both p- and n-type transistors are used in CMOSs. Most semiconductors currently used, such as those in the CPU of PCs, have a CMOS structure.

Role of SPring-8

Background

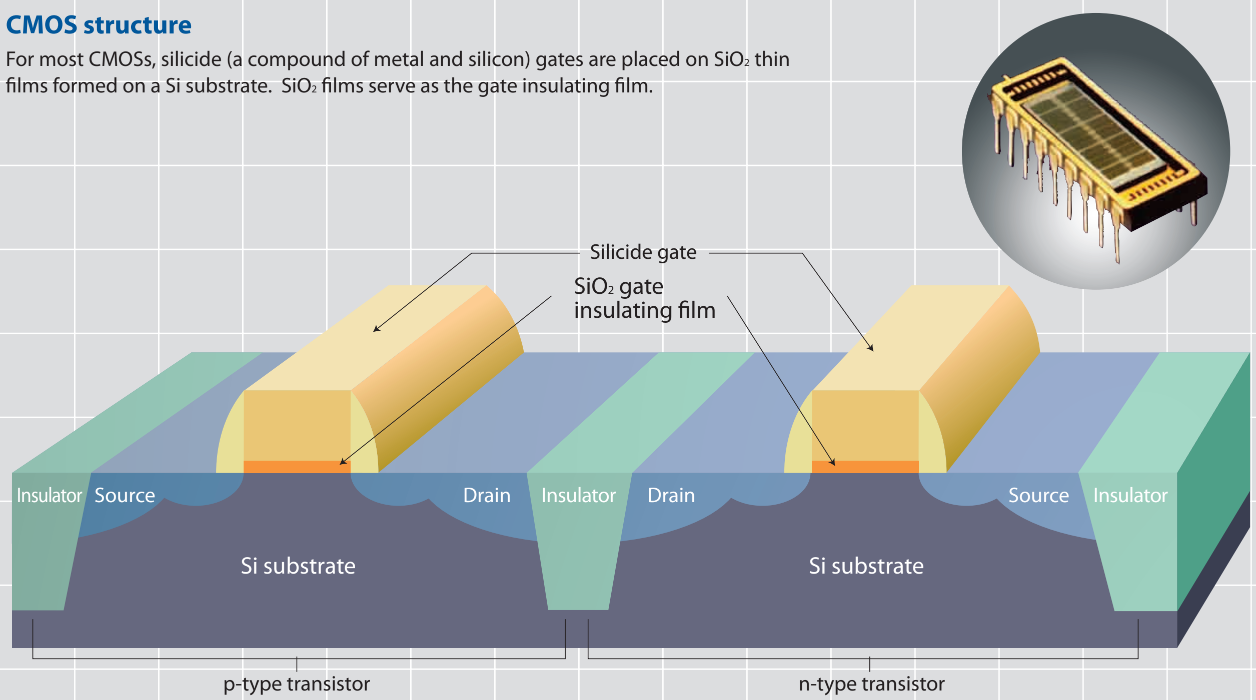
The processing speed of ICs was improved by increasing the degree of CMOS integration. It is possible to improve the operating speed by reducing the thickness of gate insulating film; however, the thinning caused the problems of increases in leakage current, heat generated and power consumed.
Moreover, it was difficult to measure the interface roughness and film density because the film thickness was 1 nm (equivalent to that of 5 atomic layers) and to determine appropriate conditions for fabricating a **gate insulating film** with decreased thickness while maintaining its high performance.

Results

When SPring-8 high-brilliance X-rays are irradiated onto an ultrathin film, an X-ray reflected from the film surface interferes with an X-ray that has passed through the film and has been reflected from its bottom surface, i.e., the border with the substrate. This **interference pattern** is used to obtain the refractive index of the film, from which the film density is calculated. In addition, the roughness of the film surface can be measured because the attenuation of the reflectance of X-rays depends on the incident angle.
We elucidated, by quantitative analysis, that the leakage current increases owing to the nonuniformity in the thickness of the SiO_2 film, which serves as the gate insulating film, and in the distribution of the added nitrogen. Thus, the optimal conditions for fabricating uniform insulating films were successfully established.

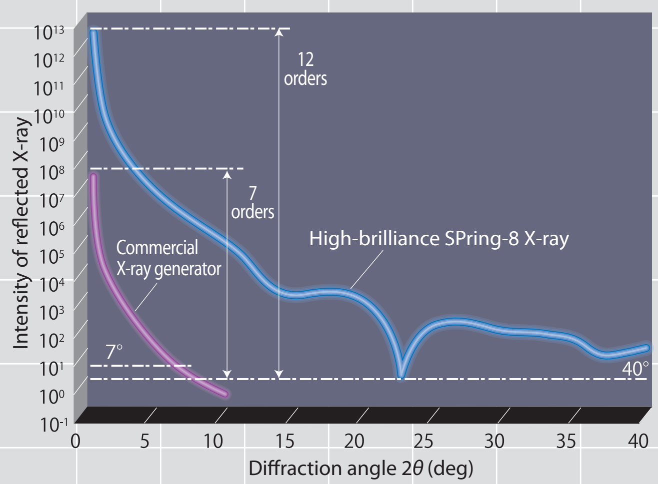
CMOS structure

For most CMOSs, silicide (a compound of metal and silicon) gates are placed on SiO_2 thin films formed on a Si substrate. SiO_2 films serve as the gate insulating film.



Evaluation of gate insulating film structure

The measurable intensity of an X-ray reflected from a thin film, which conventionally has a range of up to 7 orders, was measured over a range of 12 orders by applying the high-brilliance SPring-8 X-ray. The detectable angular range (2θ) of the reflected X-ray was widened from 7° to 40°. As a result, the evaluation of the properties of ultrathin films as thin as 1 nm became possible.



Interference pattern due to difference in film density (triple-layer model)