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INVITED: GROWTH AND PROPERTIES OF POLYCRYSTALLINE SILICON FILMS AS APPLIED TO MOS-IC TECHNOLOGY

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Various useful results have been obtained from the polycrystalline silicon technology applied to the MOS integrated circuits. The silicon-gatte device[1] is the most important of these, that offers us numerous advantages as compared with the aluminum gate device, such as low threshold voltage permitting a direct interface to TTL, elimination of critical alignment in photo-masking step (so-called self-alignment), possibility of multi-level interconnections and so forth.

A floating-gate avalanche-injection MOS (FAMOS)[2),3] and a stacked-gate avalanche-injection MOS (SAMOS)[4], both having memory storage features, are produced in the form of p-channel silicon-gate MOS. They provided us with the first successful alterable ROM on a silicon chip. In particular, the SAMOS involves two silicon gates, a control gate and a floating gate, the former being stacked on the latter isolated with a silicon dioxide layer between them. These newly-devised MOS structures were first realized by application of polycrystalline silicon technology.

The polycrystalline silicon films thus used are usually undoped as deposited. Impurities, if necessary, are doped after deposition in the source and drain diffusion step. Impurity doping during the film deposition has been studied by us[5] for a SiH_4-Ar system and also by Eversteyn and Put[6] for a SiH_4-H_2 system. B_2H_6, AsH_3 and PH_3 have been examined as the impurity sources of B, As and P. Striking effects, which proved to be useful for the fabrication of integrated circuits, have been observed on the growth rate[5),6], the electrical and crystallographical properties[5] and the etch rate[5] of the boron-doped polycrystalline silicon films.

Figure 1 shows the growth-rate vs. growth-temperature curves observed for various B_2H_6 concentrations in SiH_4-Ar gas[5]. With increasing B_2H_6 concentration, the growth rate of films greatly increases, especially in the low temperature range. The activation energy of doped growth thus decreases with lowering growth temperature, being 0.24 eV below 500°C. This value is to be compared with the undoped activation energy of 1.2 eV. When the boron-doped growth technology is applied to the integrated circuit fabrication, therefore, the growth temperature can be down to as low as 350°C, resulting in lessening in thermal damage or disturbance of device properties. Moreover, the uniformity and reproducibility of the film thickness can be improved, because the growth rate is less influenced by temperature variation.

A model proposed for these boron doping effects is that two separate decomposition processes of SiH_4 compete on the film surface containing boron, each obeying a different Arrhenius' equation. Also proposed is the model where the decomposition of SiH_4 is enhanced by the presence of holes[7]. The enhancement rate is expected to be larger for the lower growth temperatures, because the extrinsic condition holds. On the other hand, the addition of AsH_3 and PH_3 causes a decrease in growth rate, with the activation energy being unchanged from that for undoped growth.[6] This result was explained as an effect of blocking action of As and P on the growth rate.[6]

Structure of boron-doped films changes abruptly at the critical growth temperature.[5] A fiber texture consisting of rather large grains is formed at higher temperatures and an amorphous structure at lower temperatures. A subsequent heat-treatment at as low as 700°C induces recrystallization in the amorphous layers. Corresponding to this, the Hall mobility of holes increases and the resistivity of the amorphous layer is improved from more than 10 Ω-cm as grown to the order of 10^{-3} Ω-cm after heat-treatment for 30 min.[5],[6] The resistivity is almost constant for heat-treatments longer than 30 min. Again this property enables a low temperature process in the IC fabrication.

The etch rate of boron-doped films depends strongly on the growth temperature (Fig. 2) and the B_2H_6 concentration.[5] The etch rate of the heat-treated films is fairly close to that of undoped films (Fig. 2). These results suggest that electrically-inactive boron in the bulk of grains may lower the etch rate. This property enables us to make the taper etching with desirable slopes by fabricating multi-layer structures under various growth conditions.

Other application studies of polysilicon technology will be also be reviewed.[8]~[11]

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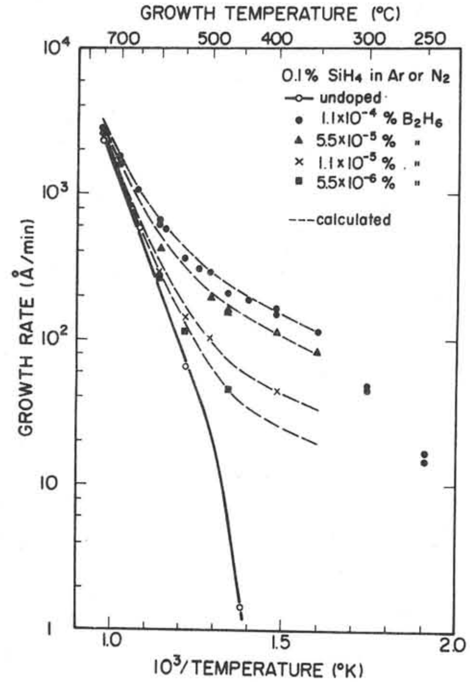

Fig. 1. Temperature dependence of growth rate for undoped and boron-doped polycrystalline silicon films.[5)]

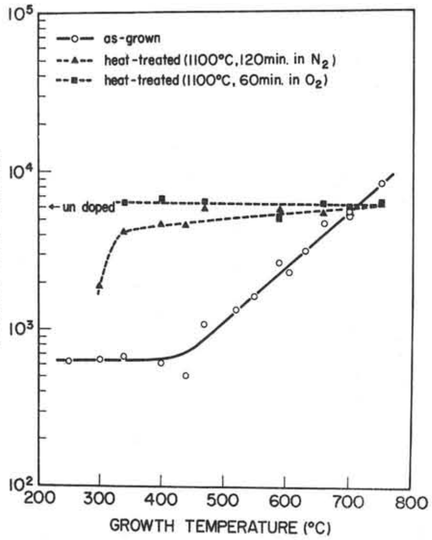

Fig. 2. Etching rate vs. growth temperature for as-grown and heat-treated poly Si films doped with boron at 1.1 x 10^{-4} mol % B_2H_6.[5)]