4.2 TEM of Defects Produced by Ion Implantation

4.2.1 Introduction

- Ion implantation for making microelectronic devised was a rather new process in 1980. You certainly produced defects in the Si matrix, and you had to get rid of them. Either by annealing after the implantation or by implanting at high temperatures. Somewhat on the side of my main work, I looked at the damage produced, employing, as I fondly believe, HRTEM for the first time.
  - Personally I wasn't all that interested, but some of my colleagues got rather excited. In particular W. Krakow and **T.Y. Tan** produced a string of papers that used the pictures I provided.
- There are two points of interest, even for the not-so-interested reader, about defects produced by ion implantation:
  1. The silicon close to the surface may become amorphous upon implantation.
  2. Behind the amorphous zone, to put it into advanced scientific terms, weird shit may happens
  - For example, if you implanted around 400 ^{0}C or annealed later at that temperature, "rod-lik" defects with stacking faults on {113} planes form. I kid you not. More to that below.
- While several publication are listed below, none of these is verydetailed. In particular, I never published the HRTEM pictures of the amorphous – crystalline interface, even so it was the first one ever taken. It showed nothing new after all, just what you would have expected. Well – it will be shown her.

4.2.1 Publications

- Below the list of publications relating to the topic. While I supplied the pictures; I had very little part in the writing of these papers.

27 FÖLL, H., TAN, T.Y., KRAKOW, W.: Undissociated dislocations and intermediate defects in As + ion damaged silicon. Symposia Proc. MRS, "Defects in Semiconductors", eds. J. Narayan and T.Y. Tan, North Holland 1981, p. 173 (1 citation)

28 TAN, T.Y., FÖLL, H., MADER, S., KRAKOW, W.: A tentative identification of the nature of < 113 > stacking faults in Si - model and experiment. as 27), p. 179 (2 citations)
Here we have a case where Google Scholar is wrong. This paper certainly has more than 2 citations. Three more recent papers on the topic that I have checked all refer r to it but are not listed by Google Scholar.
Looking at our old paper now, I have to say that it was pretty good if not yet conclusive. But that was T.Y. Tan's deep thinking and not to me.

29 KRAKOW, W., TAN, T.Y., FÖLL, H.: Detection of point defect chains in ion irradiated silicon. as 27), p. 185 (9 citations)

30 TAN, T.Y., FÖLL, H., KRAKOW, W.: Detection of extended interstitial chains in ion-damaged Si. Appl. Phys. Lett 37 (1980) 1102 (22 citations)

32 KRAKOW, W., TAN, T.Y., FÖLL, H., CHERNS, D., SMITH, D.A.: Point defects and interface imaging at the atomic resolution level. Proc. 39th EMSA Meeting, eds. G.W. Bailey (Claitors Publ. Div.), Atlanta 1981, p.116

33 TAN, T.Y., FÖLL, H., KRAKOW, W.: Intermediate defects in silicon and germanium. Inst. Phys. Conf. Ser. No. 60 (1981) 1 (7 citations)

34 KRAKOW, W., TAN, T.Y., FÖLL, H.: The identification of atomic defect chain configurations in ion irradiated Si by high resolution electron microscopy. as 33), p. 23 (7 citations)

- Certainly those are not well-read papers. To some extent this is due to i) The topic is rather special, and ii) extremely complicated. Only a handful of scientists would find it interesting.
  - This is quite true - however: The handful of scientists by now has grown to two handfuls or so. More recent papers about interstitial in Si do use terms like "interstitial chains" and so on, so we might have been on to something. Of course, nobody refers to those obscure and ancient papers. That's why I gave you a link to only one of these papers.

4.2.3 Pictures

Amorphous – Crystalline Interface

- Let's start with the amorphous – crystalline interface.

Pictures Interface
with some explanations

{113} Stacking Fault and Relatives

- Next, let's look at the {113} stacking fault. It's remarkable since no material scientist, possibly helped by bottles of the good stuff, would ever have come up with the prediction that silicon would produce a defect like that. It was weird then and it still is quite weird – after 50 years of research!
  - If you dont believe me, look at these more recent publications:

    1. H. BARTSCH, D. HOEHLa, nd G. KASTNER: Radiation-Induced Rod-Like Defects in Silicon and Germanium phys. stat. sol. (a) 88, 543 (**1984**)
    2. Seiji Takeda Seiji Takeda: The Japan Society of Applied Physics, find out more An Atomic Model of Electron-Irradiation-Induced Defects on {113} in Si
       1991 Jpn. J. Appl. Phys. 30 L639
    3. A. Parisini a & A. Bourret: Diamond hexagonal silicon phase and {113} defects. Energy calculations and new defect models.
       PHILOSOPHICMAALG AZINAE, **1993**, VOL. 67, No. 3, 605-625
    4. M.SEIBT*, J.IMSCHWEILER**and H.-A.HEFNER: FORMATION AND THERMAL STABILITY OF END-OF-RANGE DEFECTS IN Ge IMPLANTED SILICON
       Mat. Res. Soc. Symp. Proc. Vol. 316. **1994** Materials Research Society
    5. S. Takeda , M. Kohyama & K. Ibe: Interstitial defects on {• 113} in Si and Ge Line defect configuration incorporated with a selfinterstitial atom chain
       PHILOSOPH~CMAALG AZINEA , **1994**, VOL.7 0, No. 2, 287-312

    There are plenty more - just search yourself.
- What is a rod-like {113} stacking fault. To quote my own paper:
  {113} stacking faults are characterized by: (1) a prominent growth in a <110> direction and a minor growth in a <332> direction, so that the habit plane of the defect is {1113}.
  (2) The SF unfaults by a shear, which results in a unique 1/2 <110> interstitial loop.
  (3) The SF is extrinsic, and
  (4) the matrix crystal is displaced by 1/25 <11 6 >.
  And so on.
  - To repeat myself: No material scientist would ever have suggested that the Si crystal deals with unwanted interstitial an other point defects by putting them into a narrow but long rod on a {113} plane. Why, for Boltzmann's sake? It just makes no sense all. But that is what the Si crystal does. We may by now have a good if not yet perfect understanding of the structure of these beauties but still no good idea why they are formed- n the first place.
    Actually as I (meaning my co-workers) found out much later, other strange things happen involving <113> directions or planes. If you dissolve Si electrochemically, pores may form. And these pore may like to grow in certain crystallographic directions. <100> is most prominent, followed by <113>. ??? We have speculated about that but in reality we have no idea.
    Isn't that great? There are puzzles left to solve by my young colleagues. May the force be with them!
- My interest in these defects now is larger than it was then. That's why I give you some unpublished pictures I still found in my archive after 40 odd years.

Pictures {113} stacking fault / relatives