Pictures to: 4. IBM T.J. Watson Research Center

4.3.1 Pictures to Anodic Defect Etching

- As before, I will supply the pictures in the two publications plus a number of auxiliary ones never published before.

- First, the two pictures for the letter (ref. 24)

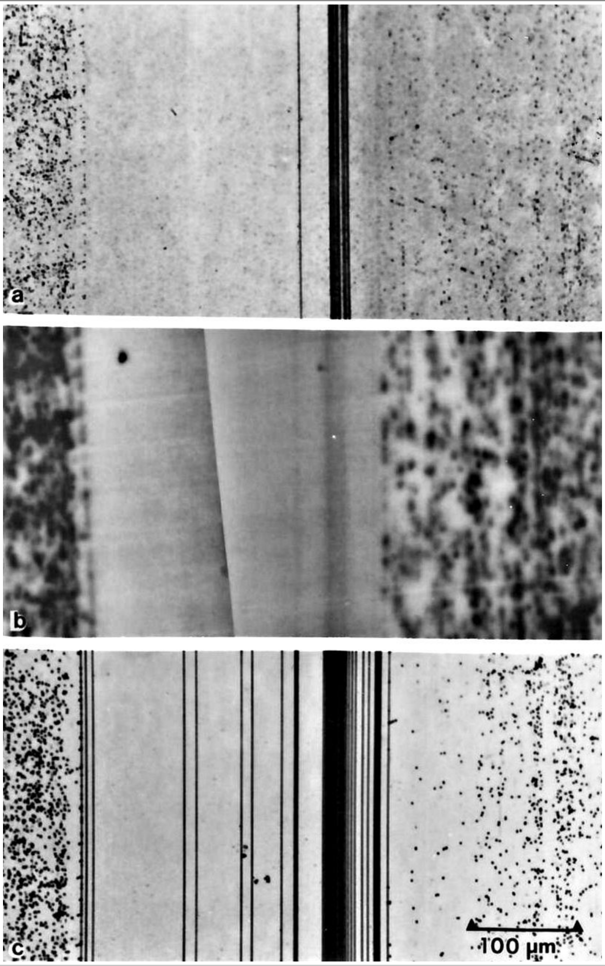


Fig. 1 In Publication 24
(a) Si ribbon anodically etched at – 0.4 V. (b) EBIC image
of adjacent area, (c) adjacent area etched at + 0.4 V.

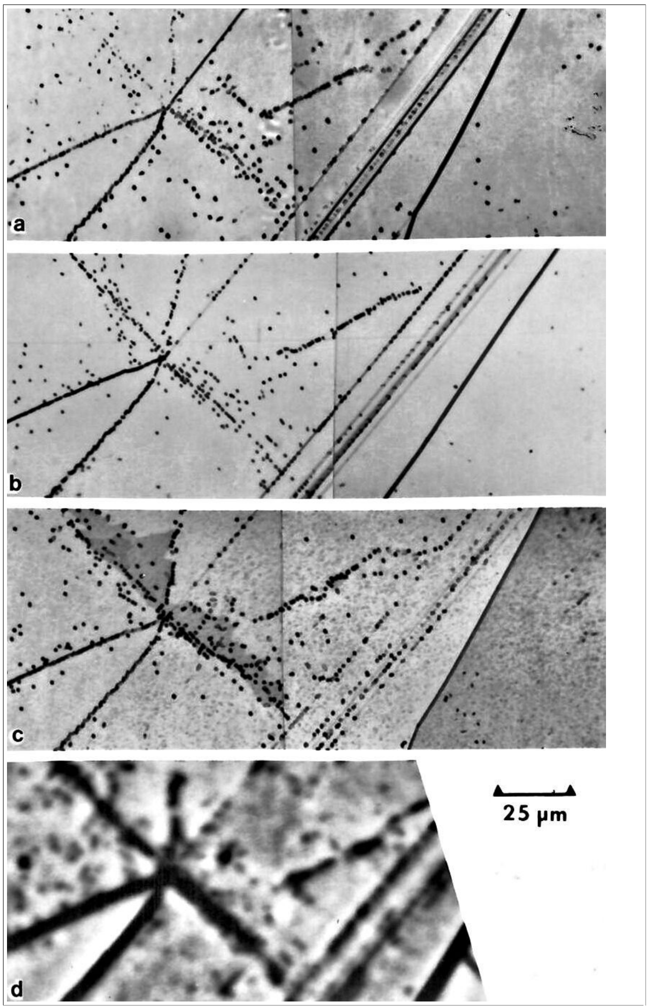
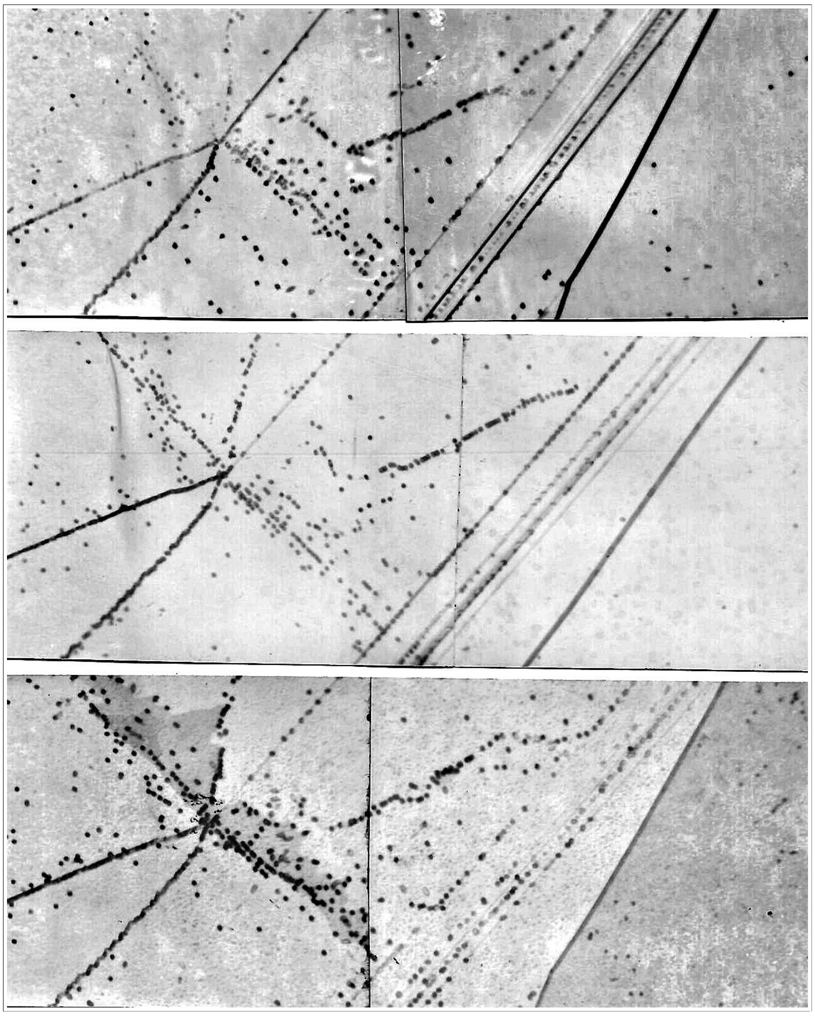


Fig. 2 In Publication 24
Same area in polycrystalline ASilicon etched chemically
(a), anodically at at + 0.4 ,. anodically at – 0.4 V(c).
Fig. 2(d) shows the EBIC image of this area.



Parts of Fig. 2 in large format
(Click to enlarge)

The pictures from the full paper (ref. 22) follow

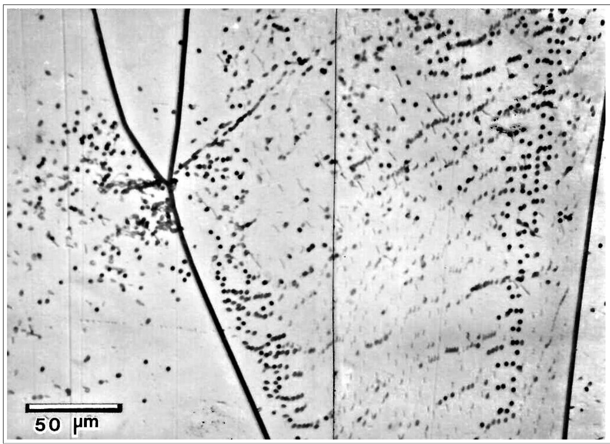


Fig. 2 in ref.22
Fig. 2. Example of anodically etched poly-Si (40 min at OV bias)

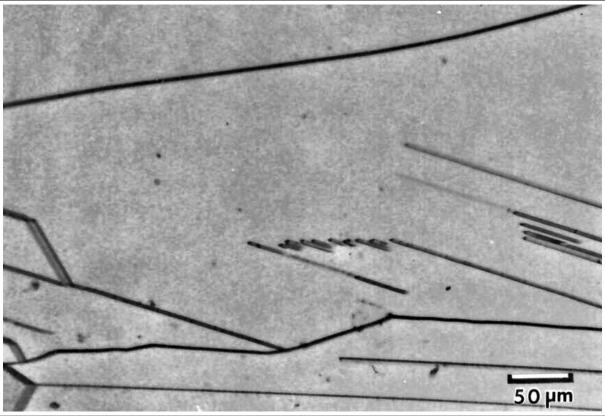


Fig. 3 In Publication 22.

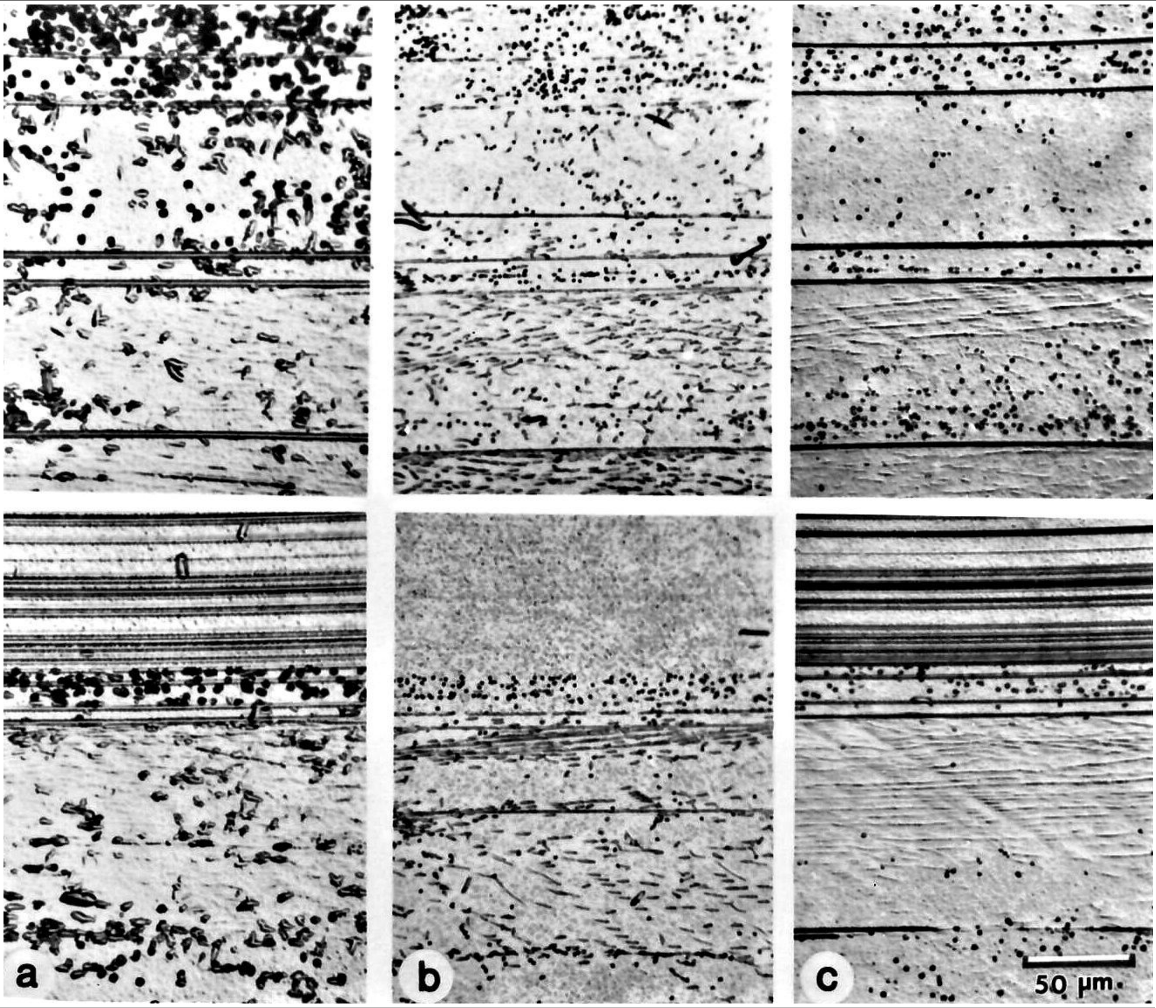


Fig. 5 In Publication 22
Fig. 5. Anodlcally etched Si-ribbon at (a) +O.SV, (b) OV, qnd (c) --0.4

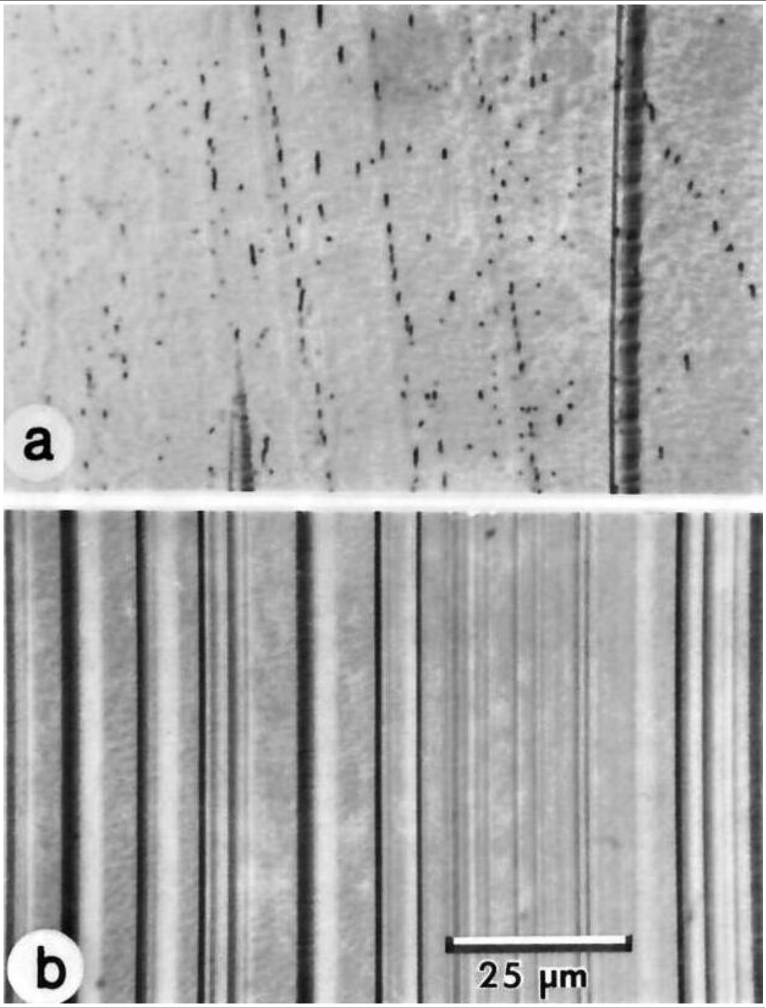


Fig. 6 In Publication 22.
Fig. 6. Si ribbon etched at 5V. In (a) dislocation etch pits are still visible whereas in a neighboring area dislocations are no longer revealed.

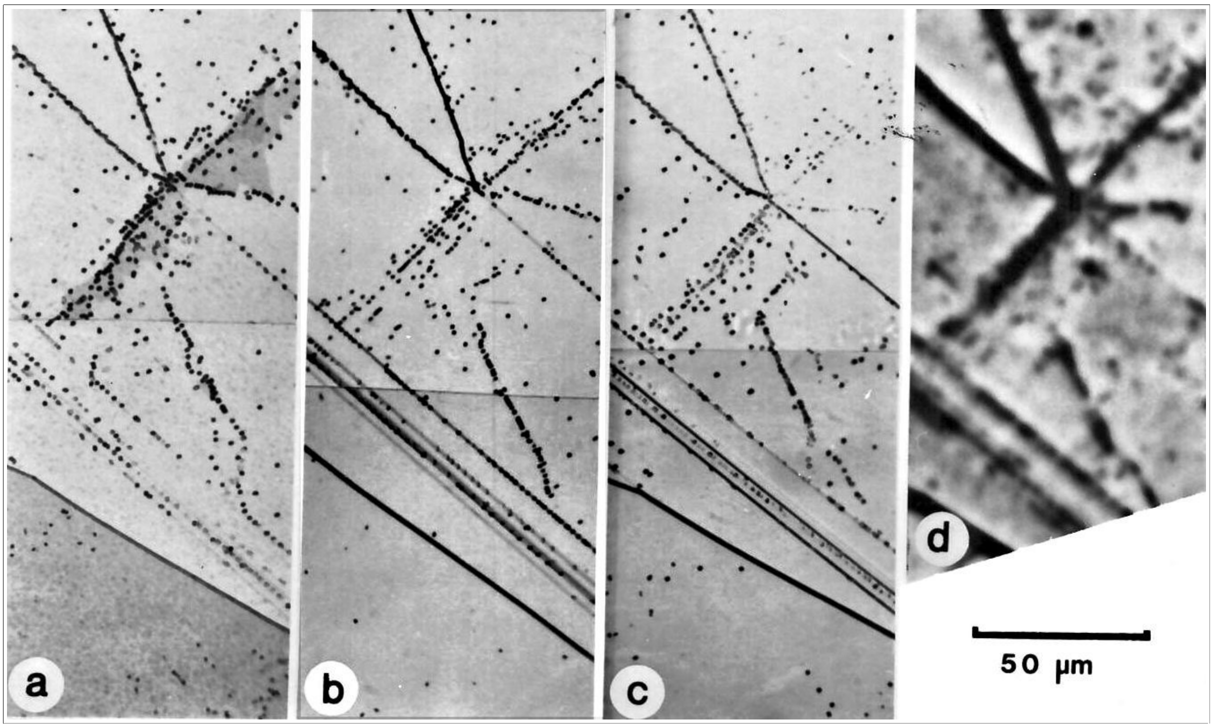


Fig. 7 In Publication 22
Fig. 7. Comparison between anodlc etching, $irtl etching, and EBIC in poly-Si. For details see text

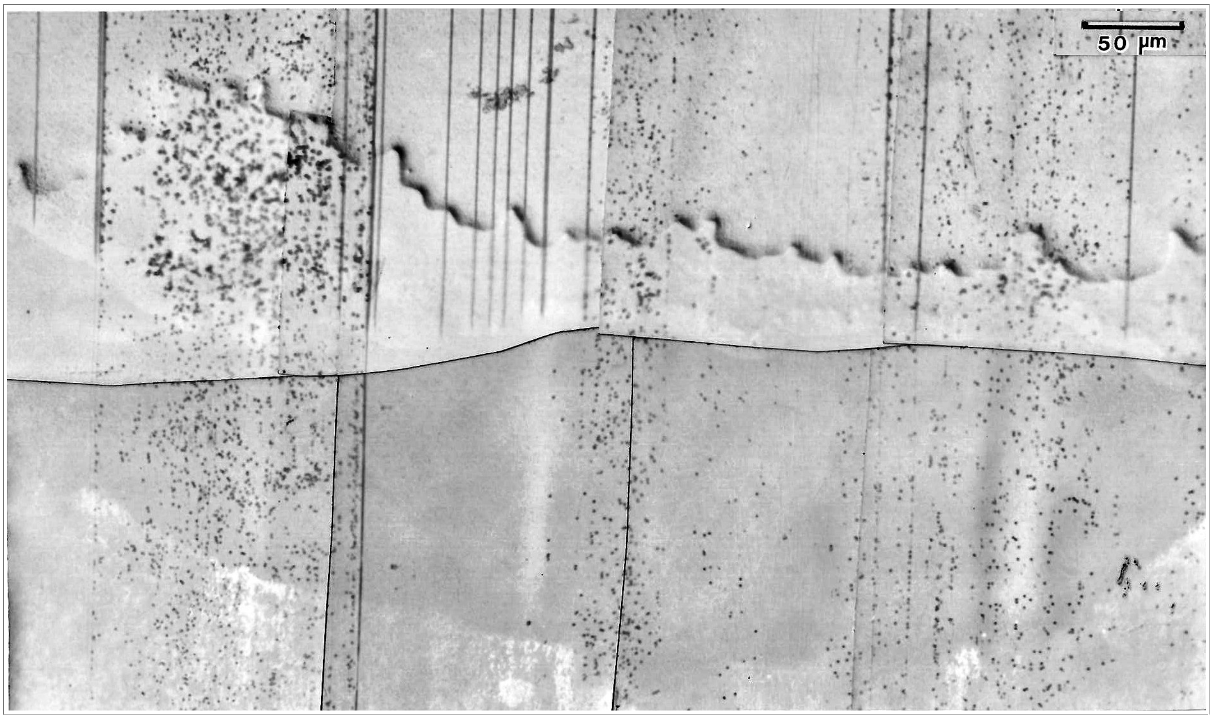


Fig. 8 In Publication 22.
Fig. 8. Comparison between anodic etching and Sirtl etching in ribbon Si.
This large size picture was scanned from the original (somewhat faded) Polaroid prints.

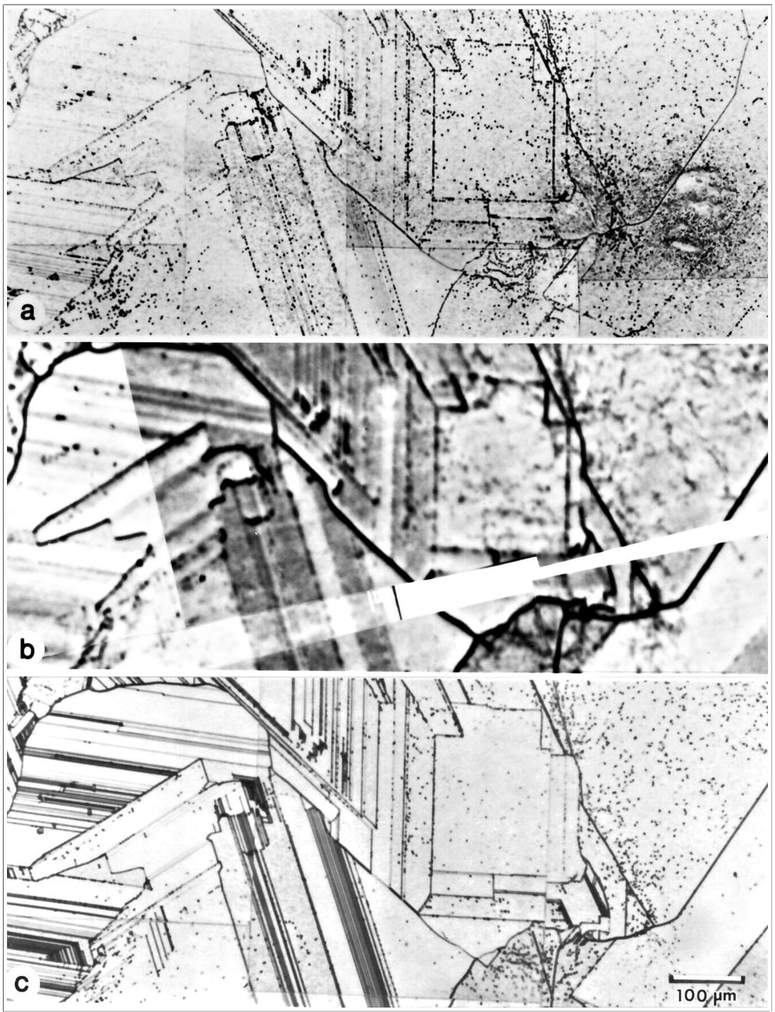


Fig. 9 In Publication 22.
ig. 9. Poly-Si etched r at --0.4V (a) and with Sirtl etch (c). Figure 9(b) shews the EBIC image of this area.

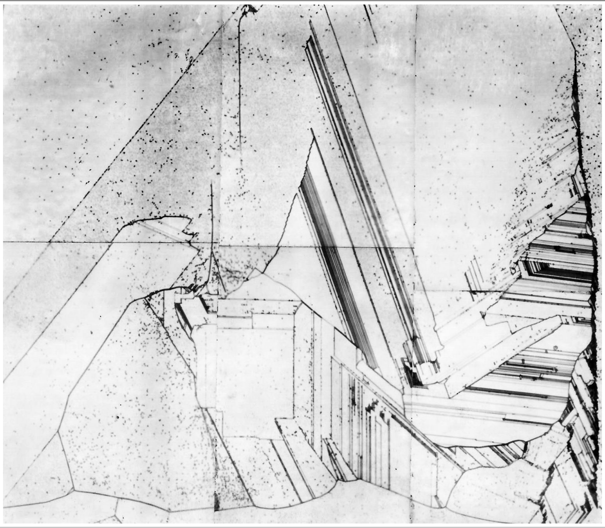


Fig 9a from above.
Scanned from the original (faded) Polaroid prints,
Shows the full area.

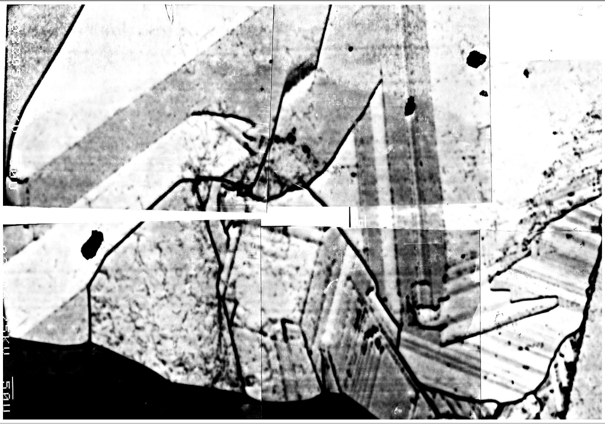


Fig 9b from above.
Scanned from the original (faded) Polaroid prints,
Shows the full area.

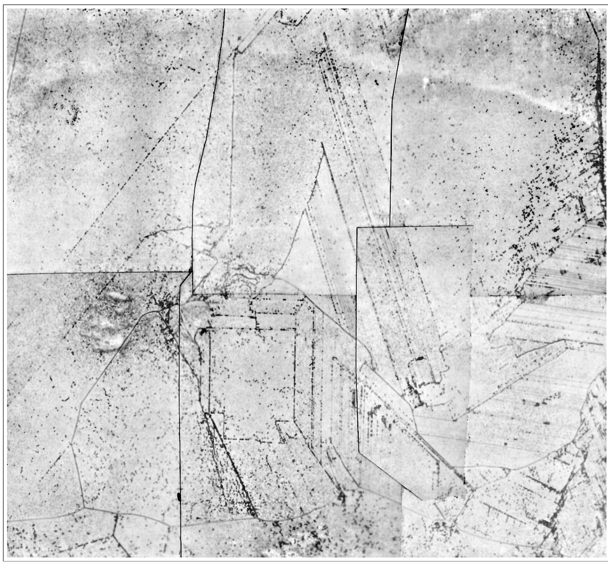


Fig 9c from above.
Scanned from the original (faded) Polaroid prints,
Shows the full area.

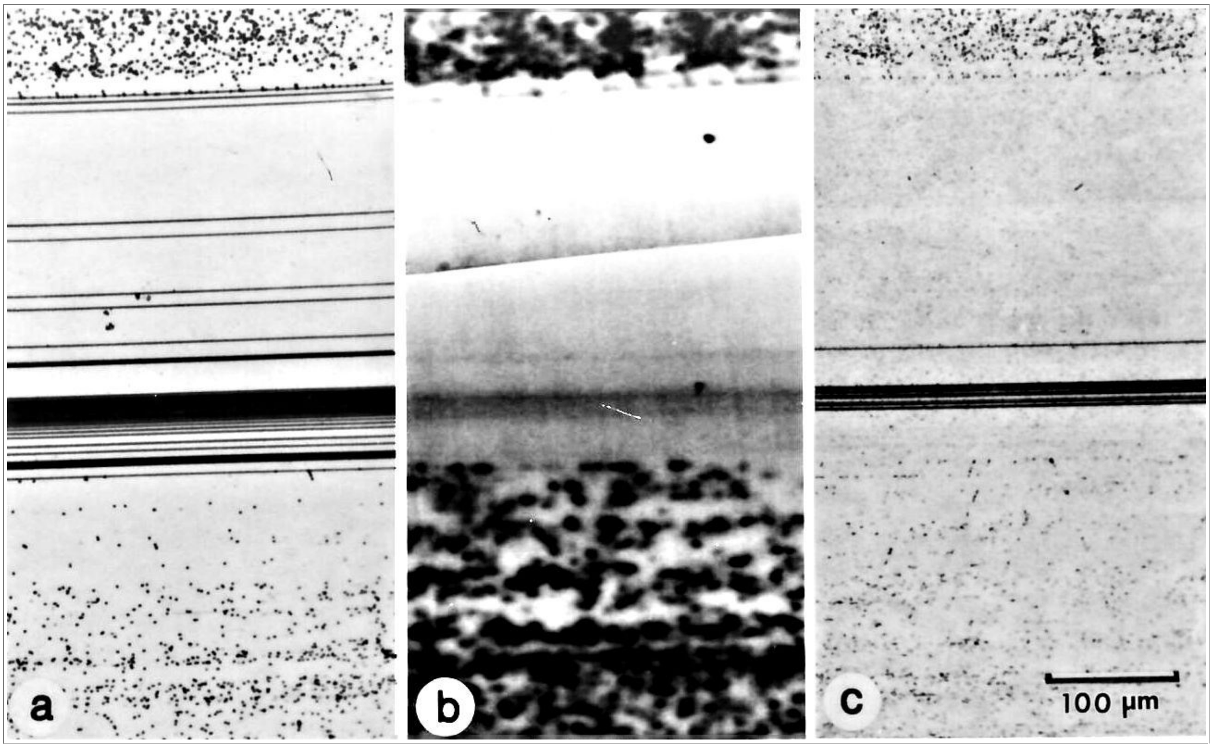


Fig. 10 in Publication 22
Fig. 10. Comparison between anodic etching at -{-O.5V (a), EBIC (b), and anodic etching at --0.4V (c) in ribbon-Si,.

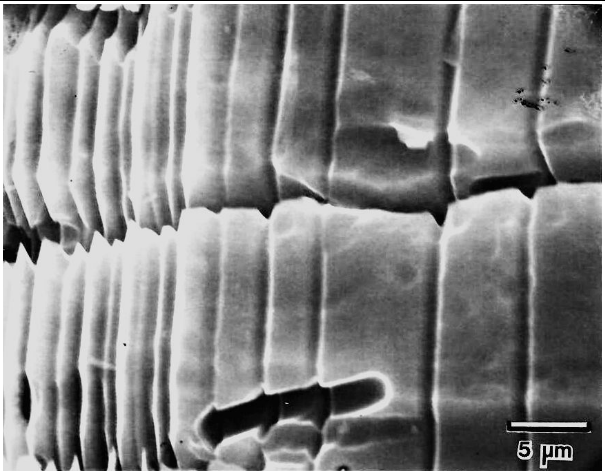
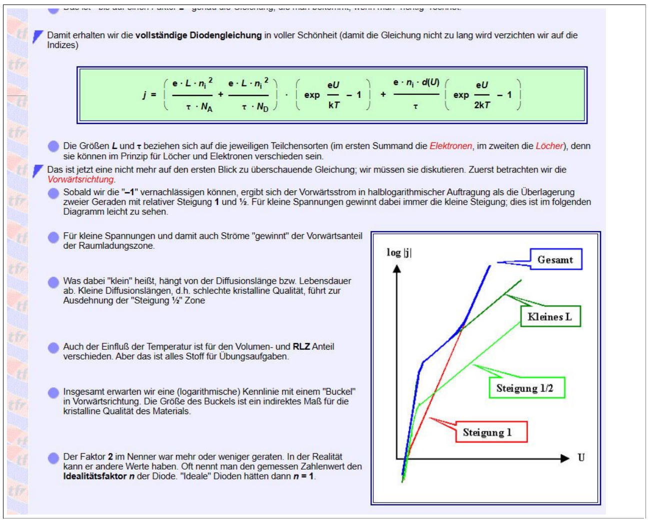


Fig 9c from above.
Scanned from the original (faded) Polaroid prints,

Finally, instead of Fig. 9 in the original paper (a drawing) I show you a piece of a Hyperscript for my students that I conceived about 20 years later.
The pictures shows about all there is to say about the mechanism of anodic etching. The IV character tics calculated are not that different
from the ones I postulated in the original Fig. 9.
Here is the link to this Hyperscript

- Notice how cunningly I distracted form the fact that I had no idea about junction theory: "A full understanding of the current - potential
curves of semiconductors with and without defects requires a sophisticated theory which is beyond the scope of this paper" , to quote myself.
However, if you want to go beyond the simple "leakage current from the space charge region" approach, it does get quite sophisticated, indeed.



Damit erhalten wir die **vollständige Diodengleichung** in voller Schönheit (damit die Gleichung nicht zu lang wird verzichten wir auf die Indizes)

$$j = \left(\frac{e \cdot L \cdot n_i^{\,2}}{\tau \cdot N_A} + \frac{e \cdot L \cdot n_i^{\,2}}{\tau \cdot N_D}\right) \cdot \left(\exp\frac{eU}{kT} - 1\right) + \frac{e \cdot n_i \cdot d(U)}{\tau}\left(\exp\frac{eU}{2kT} - 1\right)$$

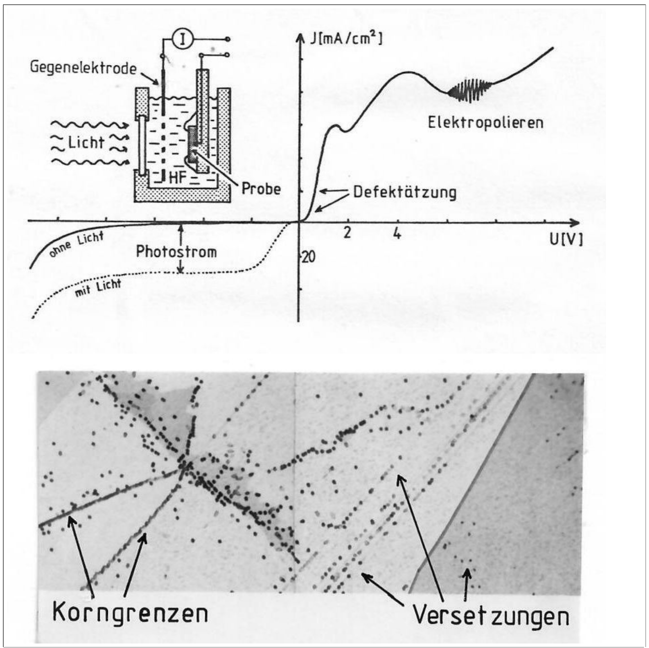
- Die Größen ***L*** und **τ** beziehen sich auf die jeweiligen Teilchensorten (im ersten Summand die *Elektronen*, im zweiten die *Löcher*), denn sie können im Prinzip für Löcher und Elektronen verschieden sein.

Das ist jetzt eine nicht mehr auf den ersten Blick zu überschauende Gleichung; wir müssen sie diskutieren. Zuerst betrachten wir die *Vorwärtsrichtung*.

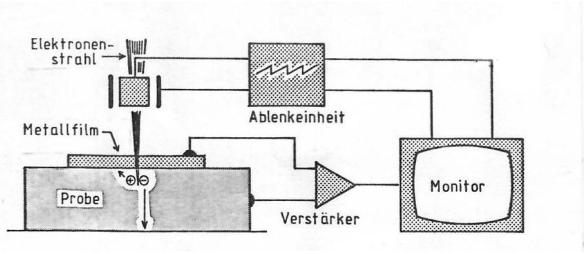
- Sobald wir die "**–1**" vernachlässigen können, ergibt sich der Vorwärtsstrom in halblogarithmischer Auftragung als die Überlagerung zweier Geraden mit relativer Steigung **1** und ½. Für kleine Spannungen gewinnt dabei immer die kleine Steigung; dies ist im folgenden Diagramm leicht zu sehen.
- Für kleine Spannungen und damit auch Ströme "gewinnt" der Vorwärtsanteil der Raumladungszone.
- Was dabei "klein" heißt, hängt von der Diffusionslänge bzw. Lebensdauer ab. Kleine Diffusionslängen, d.h. schlechte kristalline Qualität, führt zur Ausdehnung der "Steigung ½" Zone
- Auch der Einfluß der Temperatur ist für den Volumen- und **RLZ** Anteil verschieden. Aber das ist alles Stoff für Übungsaufgaben.
- Insgesamt erwarten wir eine (logarithmische) Kennlinie mit einem "Buckel" in Vorwärtsrichtung. Die Größe des Buckels ist ein indirektes Maß für die kristalline Qualität des Materials.
- Der Faktor **2** im Nenner war mehr oder weniger geraten. In der Realität kann er andere Werte haben. Oft nennt man den gemessen Zahlenwert den **Idealitätsfaktor *n*** der Diode. "Ideale" Dioden hätten dann ***n* = 1**.

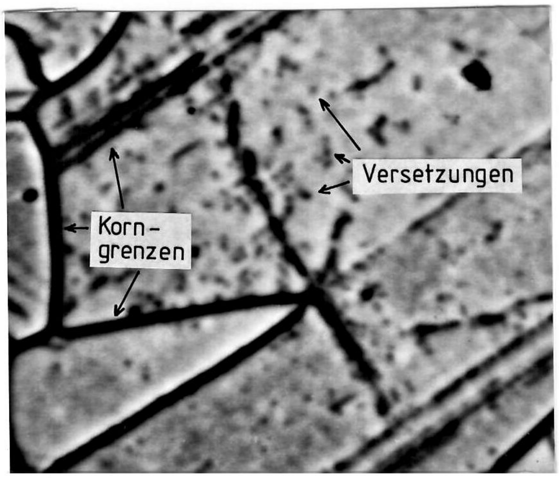
A comment to Fig. 9 in Publication 22.

Last, some auxiliary pictures. First tow pictures showing how the anodic retching / EBIC is done:

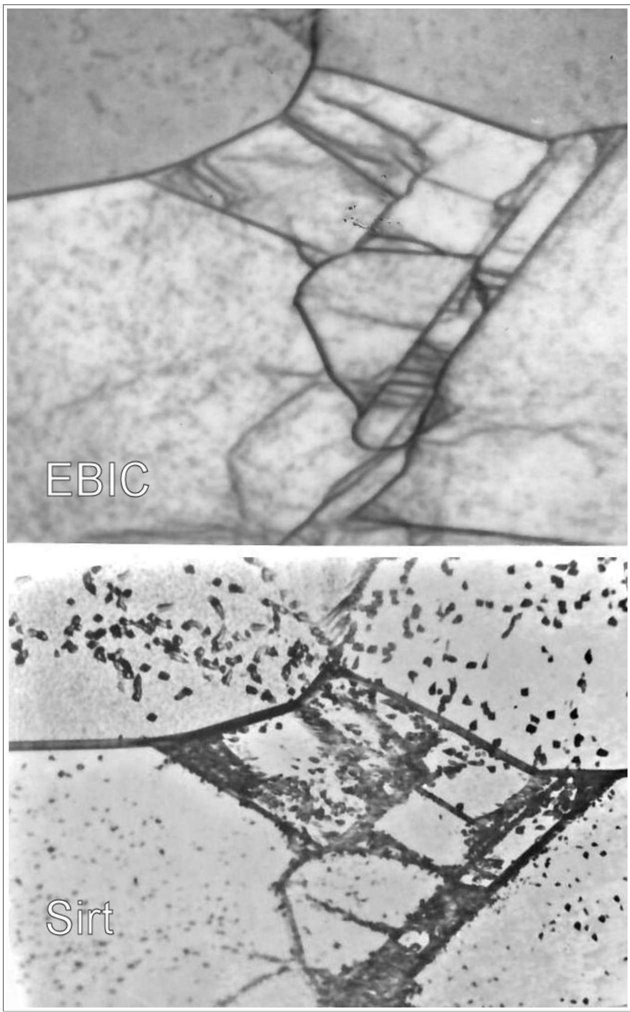


I-V characteristic of a p-Si - electrolyte contact and the working points for anodic etching

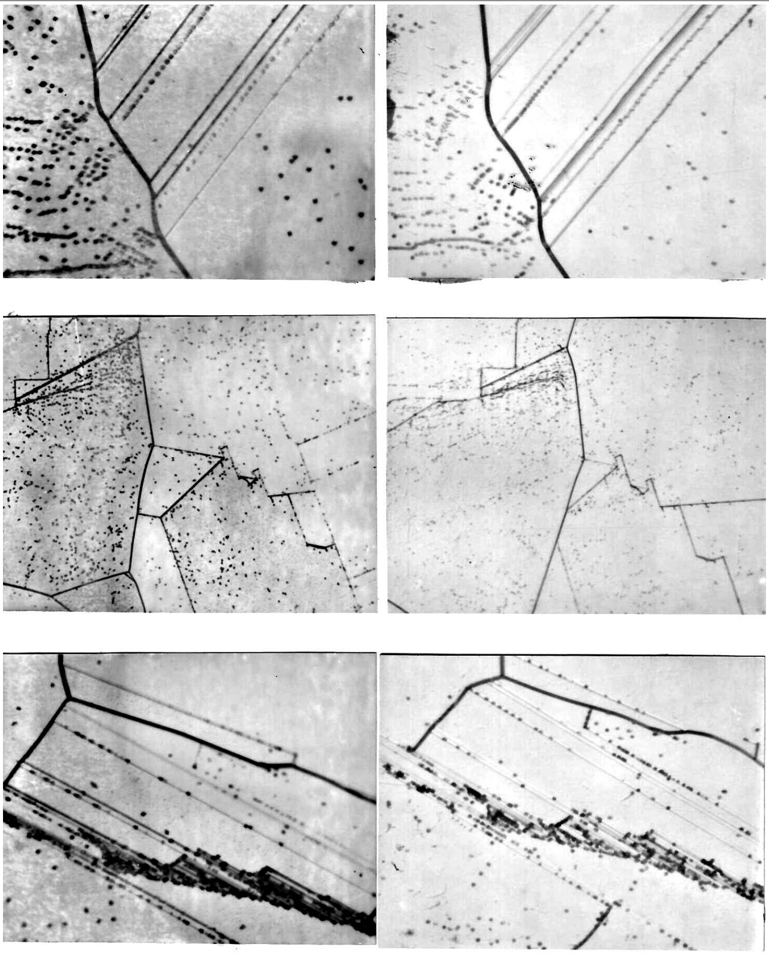




The basics of EBIC
More complex, more woork, less resolutions and far more expensive than anodic etching

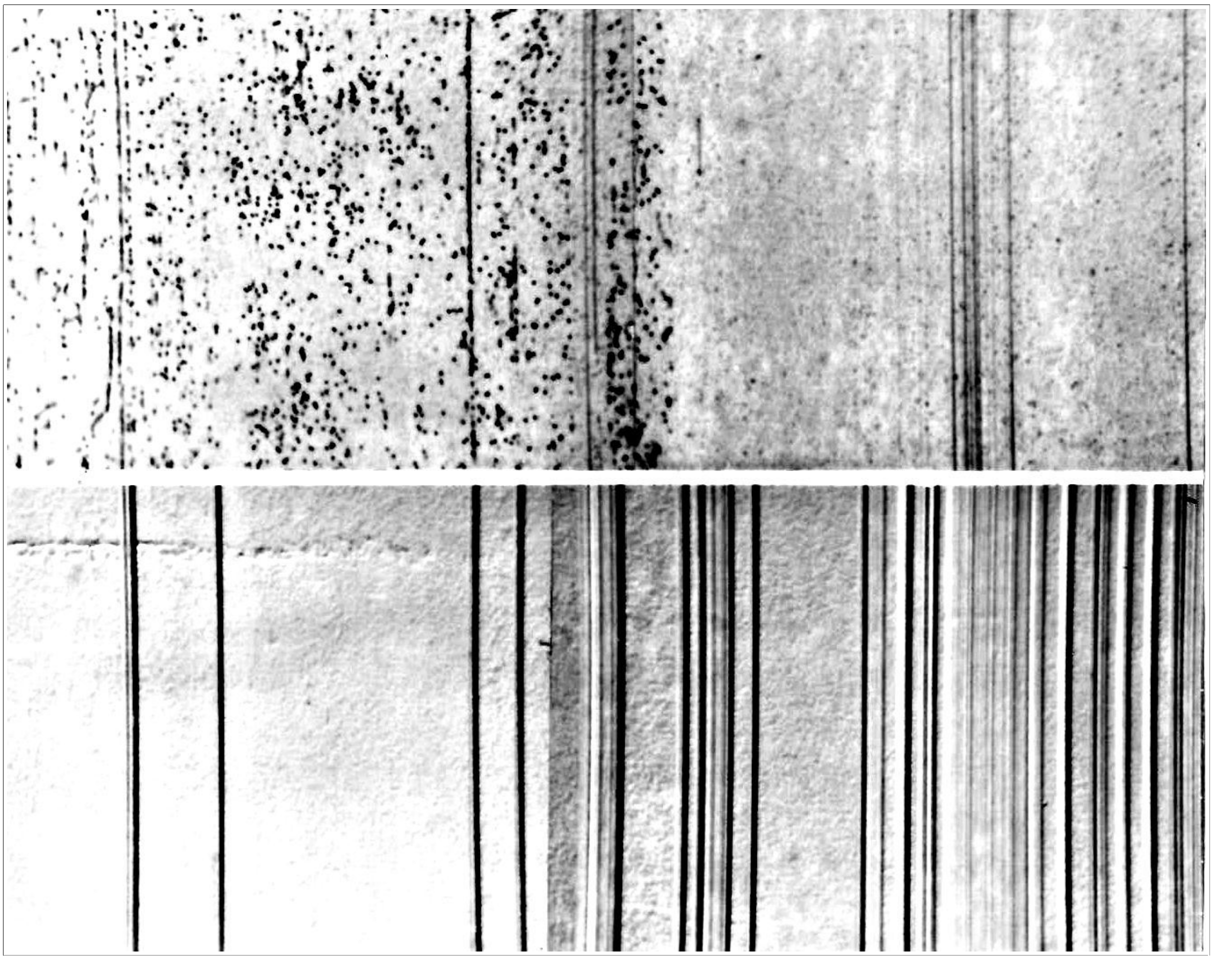


Comparison EBIC and Sirtl etching



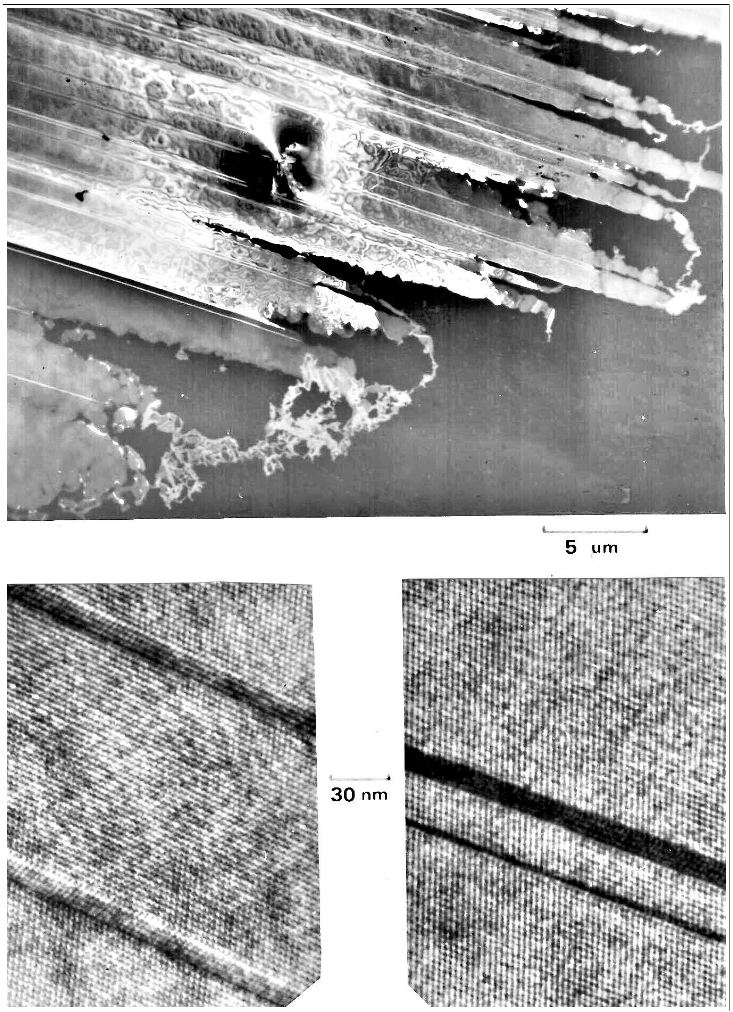
Sirtl Anodic

Comparison Sirtl etch and anodic etching



Anodic etching of twin boundaries
Top: Etching around -0,4 V shows only electrically active defects. We see dislocation pits and a few twin boundaries
Bottom Etching at higher potentials reveals all or most twin boundaries but not the other defects.

- The big puzzle was why twin boundaries did mostly not shoe “electronic activity” In the picture above, most twin are invisible in the upper part, showing only active defects. Moreover, the twin boundaries that show some activities are not prominently pictures in thee lower part. I tried to shed some light on this by doing TEM, an example is shown below.



TEN pictures from the area of active twin boundaries.

- One result was that the active regions contained a lot of twin boundaries, very close to each other. That explains (more or less) why they are hard to see at low magnification but not really why there is activity. I tend to believe that the activity is tied to contamination and that many boundaries in a given volume just attract more contamination, all other parameters being equal.

- One more picture that is of some interest

What the surface looked like after anodic defect etching
Not published. Color pictures were not accepted by most journals.

More often than not my etched (poly crystalline) specimen were rather colorful after the etching process.
That was annoying but the colored layer was easy to remove, I had no idea about the nature of these colore layers.
Later, of course, this *(nano)porous silicon layer* (***PSL***) made big waves in science; I'll come to that.