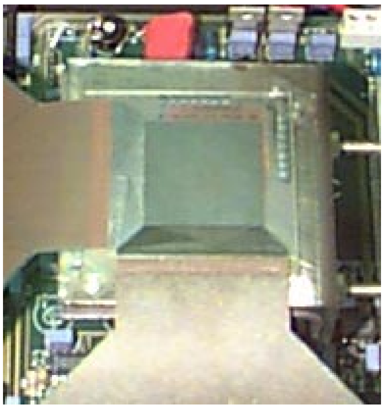
FACULTY OF APPLIED SCIENCES

Department of Electronics
and Information Systems

a-SiN:H X – Ray Sensor

Igor A. Popov



Promotor: Prof. Dr. Ir. A. Van Calster
Thesis submitted for obtaining the
Degree of Doctor in Applied Sciences

Academic year 2000

Foreword

This thesis consists of 118 pages, 43 figures and 31 tables divided between four chapters and three appendixes. Information given in appendixes is considered useful but not critical in achieving the goal of the work. Also while discussing different research / analysis methods I have limited myself to practical implementation of those, always referring to the sources containing full description of the methods. I hope that such approach has allowed me to present a comprehensive work with clearly seen core.

The ultimate goal of this work is to demonstrate the possibility of realising of an "all a-Si" direct x-ray sensor array. I think everyone would agree with the statement such as "if it *can* be done in silicon, it *will* be done in silicon eventually" but unfortunately there is quite strong opposition to the fact that *it* actually *can* be done in silicon. Naturally, before any discussion and research work on the topic can be started we have to assert our standpoint. This is the subject of the *Chapter I: Problem definition*.

Chapter I can be subdivided into three closely connected parts. First of all, it is an analysis of the current trends in the area of digital radiography in the context of the state-of-the-art systems. Such an analysis helps to understand advantages and disadvantages of the different systems as well as to answer the question on why there are so many approaches to a task of substituting "simple photo film". At the same time the role of a-Si alloys in digital radiography starts to become visible. And it is not much of a role, far too small for such a potential material as a-Si alloys. Quite naturally in the second part of the Chapter we have an in-depth look on (i) the radiation we have to deal with, (ii) why Si was never considered a real contestant for the task and (iii) what can be done to alter the current state of affairs. While dealing with these questions it becomes clear that problem is indeed not trivial, with severe, sometimes contradictory requirements to the material properties. Fortunately we are working with amorphous silicon, material of unique properties. And in order to reach our goal we will have to use these properties. This is why the third part of the Chapter is devoted to structure modification of a-Si alloys with the use of a-Si:H as a model material. a-Si is the most used material in thin-film electronics, and TFT is the most used device. This is the reason we used those to demonstrate the power of the approach. At the end of the Chapter amorphous hydrogenated silicon rich silicon nitride is introduced as a material of probable interest for us. The attractive sides of a-SiN:H includes its structural properties and its use in Thin Film Diode arrays both as a switching and sensing elements.

Before processing with x-ray sensing applications one wishes to have total understanding of a-SiN:H TFD, its performance limits and to which extent one can influence these limits. This is the subject of *the Chapter II: a-SiN:H thin films for TFD array applications*, chapter which lays technological foundation for our future work. So it starts with the overview of a-SiN:H technology. This overview includes description of the hardware used for the a-SiN:H deposition as well as selection of the film's characteristics we are going to control and respective measurements techniques. Description of the "TFD test cell" - test vehicle developed especially for a-SiN:H TFD study concludes technology overview.

The common problem of the technological experiments is the overwhelming amount of experimental data that needs to be obtained and analysed. Even for the simple PECVD reactor like one used in this work we will need thousands depositions in order to get basic understanding of the process. And yet our main goal will not be achieved. This is why the next part of the Chapter is devoted to mathematical aspects of the material science. *System of Experimental Design* and *Taboo search* are chosen to help us solve the problem of enormous amount of experimental data. Practical aspects of implementation of these methods are given in the *Appendix A*.

But the core of the Chapter II is the technology of a-SiN:H TFD. Sub-goal of this part is to develop technology processing of state-of-the-art a-SiN:H TFD. And before a-SiN:H TFD direct x-ray arrays become commercially available - state-of-the-art is LCD driven by a-SiN:H TFD. This sub-goal is reached through two level technological experiments. At the first level we select PECVD process window on the base of existing experience and reference data, keeping in mind that we want structurally stable thin films (the main goal is TFD working under x-ray irradiation, so lifetime is one of the biggest problems we will face). On the base of the first approach experiments we are able to refine our process window and tune electrical characteristics of the TFD. This tuning is achieved through modification of material as well as with optimising design aspects of the TFD. Spin-off of the work presented in this Chapter is the technology of LC display controlled by matrix of a-SiN:H TFDs - given in *Appendix B*.

Now that we have a state-of-the-art a-SiN:H TFD it is the time to return to the source of this work and have an in-depth look at the subject of *the Chapter III: a-SiN:H TFD in x-ray environment*. Chapter starts with the discussion of the experiment setup, including the available x-ray source and what and how we can measure. New test vehicle - "X-ray test cell" is also described. Special feature of this test vehicle is that it already includes different hardware simulators of pixel for x-ray sensing.

Two principally different approaches to study of a-SiN:H behaviour under x-ray irradiation are used. Firstly, there is static radiation damage experiments in which TFD is exposed to radiation without any controlled voltage on its terminals. Such experiments allow to judge on the lifetime of the TFD (quality judgement). This is quite important because electrical measurements under direct x-ray irradiation is quite difficult and time consuming exercise. Conducting such measurements on the TFD that is not fit from the lifetime point of view is just a waste of valuable time. So the study of the electrical performance of the TFDs under direct x-ray irradiation is done on the TFDs that passed first "screening" stage of experiments.

Knowledge of the a-SiN:H TFD accumulated during the work described in Chapters two and three has allowed us to start optimisation of the TFD. Although there is little that can be done with TFD operating as a switching element there is a lot we can do with sensing TFD. And this is the subject of the last part of the Chapter three. All aspects of a-SiN:H TFD, such as design, material properties, nature of the sensing effect are being analysed in order to create TFD with maximum response to x-ray irradiation. Some theoretical ideas - such as enhancing a-SiN:H x-ray stopping efficiency - could not be realised in full in the frame of this work due to lack of hardware. Yet we discuss this though we do not use it. In this work we are looking for integral approach to problem - the only possible approach. And leaving out possible answers only because of "right here right now" hardware problem just does not seem right.

Chapter IV: a-SiN:H TFD x-ray sensor array is devoted to the practical implementation of the results obtained in the course of this work. We have seen that the strongest point of a-SiN:H TFD in x-ray environment is its sensing effect. If one would like to use such TFD as a switching element, one would need to shield it from x-rays. Such an approach can not be accepted because it complicates the sensor array build -up process. This is why we have chosen to use driving strategy that is novel for digital radiography. With use of this driving strategy switching element in the pixel becomes obsolete.

New test vehicles are designed and produced in order to test our approach to the "array" and make necessary adjustments. Experimental results on pixel and array layouts, judgement on feasibility of suggested driving strategy constitute the core of this Chapter. Also 2D a-SiN:H TFD x-ray sensor prototype with customary driving and read-out electronics is described.

The *Conclusion* summarises the major results. The key points of this work that contribute to the current knowledge in the field are:

- introduction of a-SiN:H as a competitor to the "conventional x-ray sensing materials" for digital radiography;
- development of the technology processing of a-SiN:H TFD as a sensing element for the low energy 20 - 60 keV x-rays;
- introduction of the novel driving strategy that allows to utilise the unique characteristics of a-SiN:H TFD in the large area array applications

Other significant points include:

- practical application of structure modification to a-SiN:H thin films;
- development of a-SiN:H technology suitable for TFD driven LCD;
- integration of System Experimental Design with Taboo Search into real life technology process

The results of this work were discussed at:

- Society for Information Display meetings in 1995 - 1996,

- The International Society for Optical Engineering (SPIE) meeting in 1998
- International Congress on Imagine Science in 1998
- Material Research Society meeting in 1998- 2000

International seminar on Noise and Degradation processes in Semiconductor Devices, in 1997 - 1999