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Production solutions in excimer laser thin film crystallization

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Abstract

Excimer laser crystallization of thin film amorphous silicon has become a key technology in manufacturing of high-resolution low-power consumption thin film transistor displays. Lambda Physik and its Beam Delivery Systems Department MicroLas are leading the efforts to develop complete laser-optical system solutions comprising uniformity, productivity and economic aspects of this UV–laser process. This paper will present latest achievements in high-power excimer laser and illuminator design to address the production requirements of thin film crystallization and will look at challenges to meet future requirements.

Keywords: Excimer laser annealing; ELA; SLS; Poly-silicon; LTPS

1. Introduction

Low-temperature poly-silicon (LTPS) is used in about 4% of all thin film transistor liquid crystal displays [1]. Advantages of LTPS compared to amorphous silicon (a-Si) are obvious since mobilities of charge carriers are limited to about 1 cm^2/V s when using a-Si [2] whereas LTPS can have similar qualities as crystalline silicon with mobilities up to 500 cm^2/V s [3]. For generation of LTPS, many different approaches exist: laser crystallization is one of the most promising regarding the quality, i.e., grain size and mobility. A good overview about recent crystallization techniques can be found in Ref. [4].

Laser crystallization itself can be divided into many different techniques depending on which laser is used and to which beam shape the a-Si film is exposed. Regarding the crystallization process, after a short time of laser irradiation, spontaneous nucleation follows seeded grain growth. If solid silicon is available as seed within the molten area, the direction of crystalline grain growth determines the size of the obtained grains. In general, lateral crystallization is advantageous compared to the vertical one.

Next to poly-silicon quality, throughput is most important for production solutions which is not only influenced by the average power of the applied laser but also by the chosen process. Here, we want to present the ability of excimer laser-based systems and compare two different processes: Excimer laser annealing (ELA) and sequential lateral solidification (SLS). The ELA technique generates poly-silicon layers with high homogeneity of morphologic and electronic properties. The crystallized layers are the established basis for the fabrication of thin-film transistors (TFT) for active matrix displays. The more recent SLS process adds to the ELA technique an improved and flexible crystallization process that enables higher mobilities for the fabrication of systems-on-substrate.

2. Established line beam technique ELA

Laser crystallization for low-temperature poly-silicon generation in the display industry of Japan, Taiwan and Korea is governed by annealing systems comprising Microlas Line Beam optics, driven by Lambda Physik excimer lasers and integrated by Japan Steel Works (JSW) [5,6] since 7 years. The annealing process is a near-complete melt process that requires pulses with low-energy variation—especially without pulse energies exceeding the complete-melt threshold. The Lambda Steel 2000 with <1.8% (σ) pulse energy fluctuation has proven to meet these requirements when emitting 1 J pulses with 300 Hz repetition rate.

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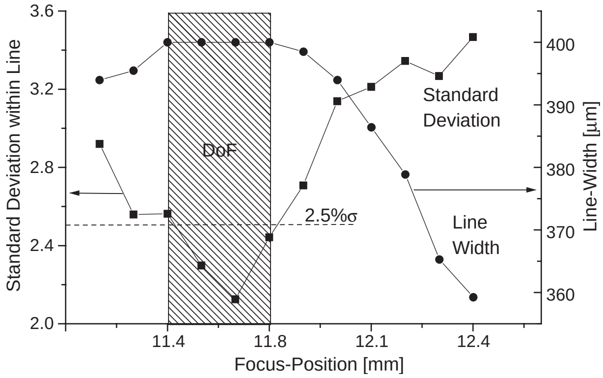

Fig. 1. Depth of focus with standard line beam systems.

The optical system itself projects a narrow line on the substrate that can be scanned across the silicon film. It makes use of the incoherence of excimer laser light that allows sufficient homogenization for the fluence-sensitive process and interacts efficiently with the amorphous silicon film due to its high absorption coefficient of $\alpha=6\times10^{-6}$ cm^{-1} at 308 nm. It consists of a flexible arrangement of cylinder-lens homogenizers and one-dimensional projection optics. Homogeneities of 2.5% (2σ) are as well possible as a ramp profile to allow slowly increasing fluence when scanning the substrate with multiple overlapping of the line-shaped beam. A depth of focus of several hundreds of micrometers allows easy process control (see Fig. 1).

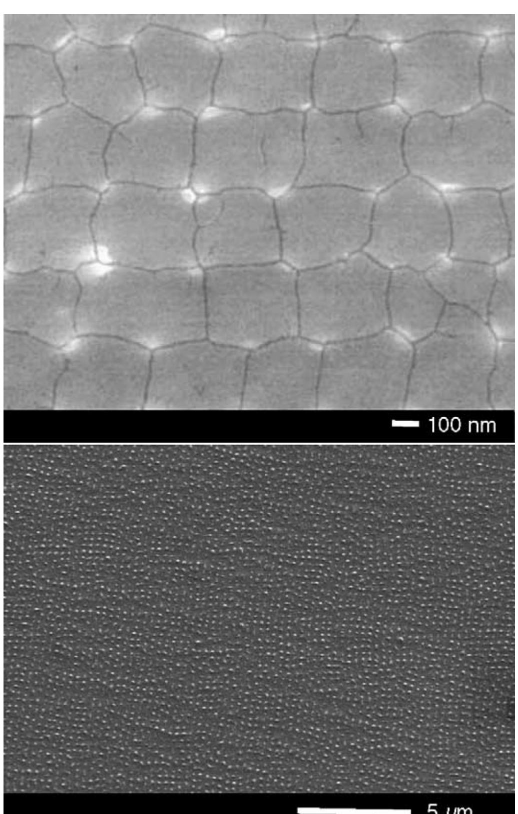

Fig. 2. SEM image after Secco etching of line beam crystallized p-Si. Top: high resolution (courtesy of JSW). Bottom: low resolution (MicroLas-Lab).

Modern systems are equipped with alignment tools and process monitoring devices like a beam profiler and on-line pulse energy meters.

2.1. Results of line beam crystallization

The line dimension of 465 mm length and 0.4 mm width results in a crystallization speed of 28 cm^2/s at 300 Hz repetition rate when overlapping 20 pulses per location. The crystallization result is a homogeneous poly-silicon-film (see Fig. 2) with about 0.3×0.3 μm^2 grain size enabling approximately 100 cm^2/V s electron mobility [4].

3. SLS process for better yield

As well known from literature [7,8,9], lateral crystallization after completely melting the film in well-defined areas with sharp transitions between liquid and solid silicon produces larger grains than vertical crystallization seeded by solid silicon at the Si-substrate interface due to near-complete melt (ELA). The required sharp transitions can be generated by a high-resolution mask projection. If the mask design is appropriate and its repeated projection is adding seeded crystallites to grains generated with the previous pulse, the process is called sequential lateral solidification (SLS) [10]. The MicroLas system CrystaLas as shown in Fig. 3 makes it possible to employ this SLS process to produce high-quality poly-silicon films on substrates with theoretically unlimited size.

In contrast to the established Line Beam technique, SLS systems are still under evaluation for mass production, but in addition to larger grain sizes, other advantages concerning throughput, panel size capability and flexibility are already obvious:

- Mainly due to the fact that with a less amount of pulses, each location on the substrate can be completely

Fig. 3. MicroLas optics module for SLS crystallization: CrystaLas.