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Formation and characterization of silicon films on flexible polymer substrates

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Abstract

Polysilicon thin film transistors on flexible substrates are of considerable interest for applications in flexible displays. This paper investigates the formation of nanocrystalline silicon on flexible, transparent polymer substrates. An 800-nm layer of amorphous silicon was deposited on a polyimide substrate followed by a 20-nm layer of aluminum. Samples were rapid thermal annealed at 900 °C for 20 s, forming silicon nanocrystallites in a porous amorphous silicon film. The films were analyzed using Rutherford backscattering spectrometry, Raman Spectroscopy and cross-section transmission electron microscopy. A mechanism is proposed for the formation of silicon nanocrystallites and pores in the a-Si layer.

Keywords: Metal induced crystallization; Flexible substrates; Polyimide

1. Introduction

Hydrogenated a-Si thin film transistors (TFTs) are used as switching elements for pixels in active-matrix liquid-crystal displays (AMLCDs). Poly-Si TFTs, with up to 200 times greater mobility than a-Si TFTs, are preferred because they enable integration of TFTs and IC driver circuits, thus reducing fabrication costs [1]. Poly-Si fabrication techniques include solid phase crystallization (SPC), where a-Si is annealed at temperatures ~600 °C for several hours to form poly-Si [2]. However, SPC produces poly-Si with a large number of in-grain defects [1]. Excimer laser annealing (ELA) is another recrystallization technique, where nano-second-pulse excimer lasers transform a-Si to poly-Si without damaging the substrate [3]. However, issues such as high manufacturing cost and lack of poly-Si grain uniformity over large areas remain [4]. Another approach used to obtain poly-Si at considerably lower temperatures and anneal times is metal induced crystallization (MIC) [4], where a metal serves as a seed layer for crystallization. Silicide forming metals like Pd, Ni [5], and non-silicide forming metals like Al [6], Ag [7] and Au [5] have been used to crystallize a-Si.

There is considerable interest in fabricating TFTs and other electronic devices on flexible substrates. Flexible display technologies offer lightweight, portable devices to consumers with the added advantage of low manufacturing cost [8]. Although polymer films are clear enough to replace glass, their low glass transition temperatures (T_g) render them unstable at high temperatures and long anneal times. The challenge is to crystallize amorphous silicon without deforming or changing the properties of the polymer substrate.

2. Experimental

A flexible polyimide film, marketed by DuPont as Kapton® Type HN, was used as the substrate. The film is

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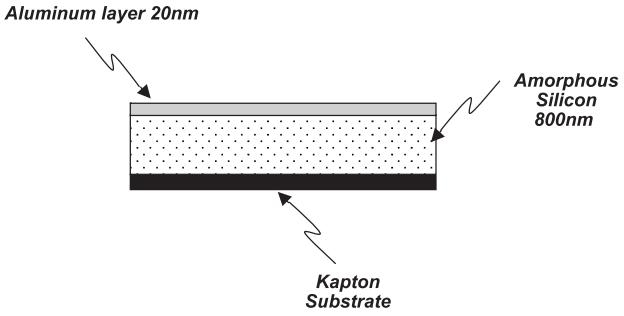

Fig. 1. Schematic showing Al/a-Si/Kapton layers.

175 μm thick with a glass transition temperature between 360 and 410 °C. Depositions were performed at room temperature, using a CHA 600 SE electron-beam evaporator at a base pressure of 3×10^{-6} Torr. 800 nm of a-Si was deposited on the substrate followed by 20 nm of Al (Fig. 1). Samples were then annealed in a nitrogen environment at 900 °C for 20 s.

Sample thickness and composition were analyzed using Rutherford backscattering spectrometry (RBS) at 2.0 MeV and 8° tilt. RUMP (Rutherford Universal Manipulation Program) software [9] was used to simulate and match the experimental RBS spectra. Sample crystallinity was analyzed using Raman spectra collected in a backscattering micro-Raman configuration, using a 0.275-m SpectraPro-275 Triple grating monochromator with a liquid nitrogen cooled Roper Scientific 7088-0001 CCD. Laser excitation was accomplished using the 514.5-nm line from a Coherent Innova 90 Ar+ source, with a power of approximately 5 mW. Cross-section transmission electron microscopy (XTEM) was performed, using a Philips CM200 TEM operated at 200 kV, to investigate the microstructure of the samples.

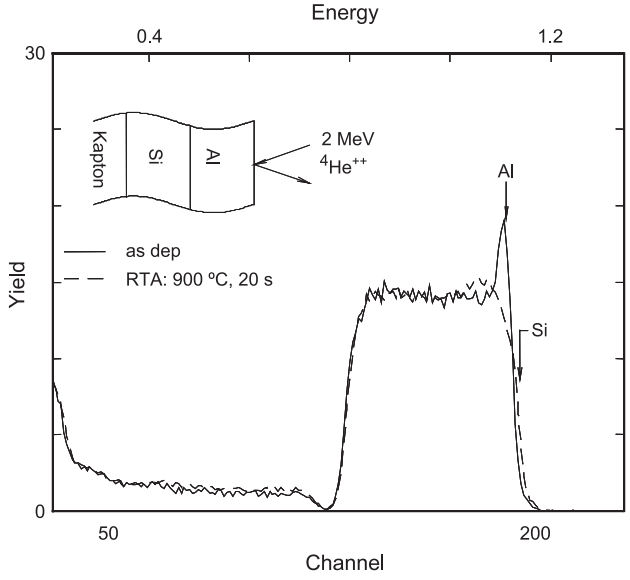

Fig. 2. RBS spectra from the as-deposited (solid line) and annealed (dashed line) Al/a-Si/Kapton samples at 2 MeV and 8° tilt.

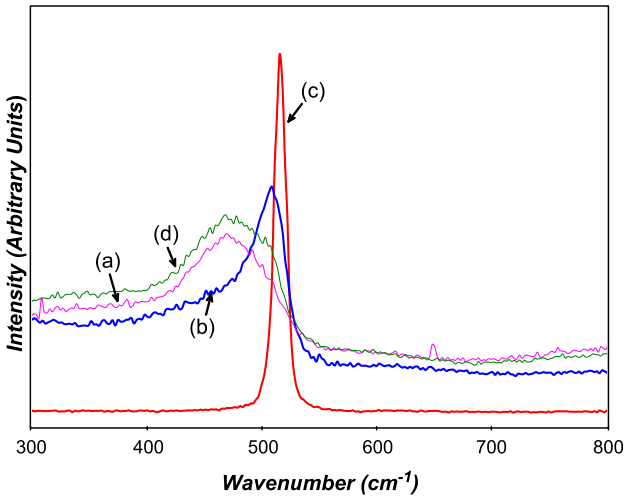

Fig. 3. Raman spectrum (a) is from the as-deposited sample showing a broad peak at 480 cm^{-1}. Spectrum (b) is from the annealed sample showing a nanocrystalline silicon peak shifted downwards by 7 cm^{-1} with respect to the peak in spectrum "c". Spectrum (c) is from bulk single-crystal silicon, with a sharp crystalline peak at 520 cm^{-1}. Spectrum (d) is from an annealed sample without an Al layer. A broad curve is seen at 480 cm^{-1}.

3. Results

RBS spectra from as-deposited and annealed samples are shown in Fig. 2.

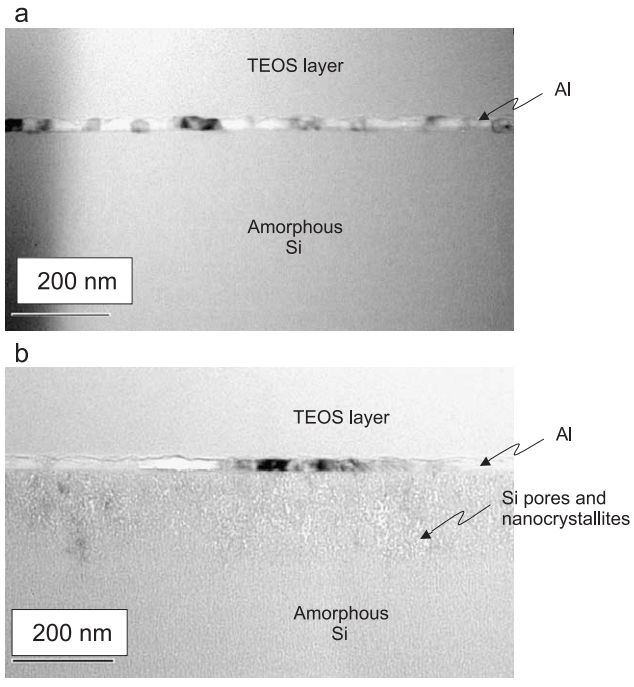

Fig. 4. XTEM micrographs of Al/a-Si/Kapton (a) as deposited and (b) annealed. The substrate is not visible in these micrographs.