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Laser annealed HWCVD and PECVD thin silicon films. Electron field emission

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Abstract

Electron Field Emission (FE) properties of various laser annealed thin silicon films on different substrates were investigated. HWCVD microcrystalline and PECVD amorphous silicon films were irradiated with Nd:YAG and XeCl Excimer lasers at varying energy densities. Encouraging FE results were mainly from XeCl Excimer laser processed PECVD and HWCVD films on metal backplanes. FE measurements were complemented by the study of film surface morphology. Geometric field enhancement factors from surface measurements and Fowler-Nordheim Theory (FNT) were compared. FE properties of the films were also found to be particularly influenced by the backplane material.

Keywords: Amorphous silicon; Laser processing; Field emission; Fowler-Nordheim

1. Introduction

For a number of years there has been interest in electron field emission from cold cathodes for flat panel display (FPD) technologies. Various materials have the potential to become efficient devices for FPDs [1–3]. These technologies are expensive to develop to an industrial capacity. Therefore the ability to develop a FE cold-cathode based on established and widely utilised material and techniques, such as amorphous Si and laser processing respectively, is a very attractive concept. Preliminary research in this area has been carried out by the Universities of Surrey and Dundee [4,5].

2. Experimental details

The HWCVD deposition system contained two straight tungsten filaments: 0.5 mm diameter, 8 cm length. These were placed between the substrate holders. The filament to substrate distance was kept constant at 5 cm. Filament temperature was varied between 1700 and 2000 °C. Substrate temperatures were varied between room temperature and 500 °C. SiH_4, diluted with H_2, was introduced and the total gas pressure was varied between 30 and 200 mtorr. Amorphous to microcrystalline phase was grown by increasing H_2/SiH_4+H_2 ratio (from 5–97%), increasing crystalline fraction with H2 dilution was previously confirmed by Raman spectroscopy [6]. Silicon films were deposited at thicknesses between 0.1 and 5.5 microns on Cr, Mo, Ti and V backplanes — of 100 nm thickness, prepared by sputtering on Corning 7059 glass substrate.

PECVD depositions were carried out at substrate temperature of 250 °C, RF power 6.5W and a pressure of 150 mtorr. H_2/SiH_4+H_2 ratios were varied from 10% to 67%. All film thickness were 100 nm, on chromium and molybdenum backplanes (100 nm), which were previously prepared by sputtering onto a Corning 7059 glass substrate.

The beam from a 10 Hz Q-switched Nd:YAG 1064 nm laser with a pulse duration of 8 nS was separated by beam splitters and recombined as a 3-beam interference pattern to produce a periodic array of geometrically sharp tips to allow FE based on Fowler-Nordheim Theory. The thin film samples were irradiated at a feed through rate of 2 mm/s with energy densities in the range 140 to 250 mJ/cm^2 for PECVD a-Si:H and 210 to 250 mJ/cm^2 for HWCVD μc-Si:H films.

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Excimer laser annealing (ELA) is an established process for crystallisation of a-Si:H [5,7]. The irradiation was carried out using a XeCl Lamda Physik LPX 200 with 248 nm wavelength and Gaussian distribution. Laser energy densities were typically in the range 100 to 264 mJ cm^{-2}. The samples were again fed through at a rate of 2 mm/s. All laser irradiations, with both types of laser were carried out in atmosphere.

Field Emission measurements were carried out in a vacuum better than 4×10^{-6} mbar. A stainless steel hemispherical probe with a diameter of 5 mm, or a planar probe, was positioned at a distance of between 30 and 50 μm from the surface and a potential applied between the probe (anode) and sample (cathode). This method is proven for FE measurements [8]. Applied field was increased every 30 s and corresponding current measurements were taken. Our threshold for FE is defined as the applied macroscopic field that produces a steady emission current of 1 nA or greater.

3. Results and discussion

3.1. Nd:YAG irradiated HWCVD and PECVD

A periodic array of features with 500 nm spacing was created during Nd:YAG 3-beam interference irradiation of HWCVD μc-Si:H on Cr backplanes. Increasing the energy density of the laser (210 to 250 mJ/cm^2) led to faster increase in feature radius than in height. Hence they were not sharp enough to take advantage of the Fowler-Nordheim (FN) tunnelling effects usually associated with tip like structures in FE cathodes. This may be why no field emission was observed from these films at applied fields up to 60 V/μm.

Nd:YAG 3-beam interference pattern was also used to irradiate PECVD a-Si:H films of 100 nm thickness on a Cr backplane, also 100 nm. Energy fluence ranged from 140 to 250 mJ/cm^2. Field Emission measurements were carried out with an anode–cathode spacing of 30 μm, up to fields of 60 V/μm. The most promising FE results were observed from PECVD a-Si:H irradiated at a laser fluence of 140 mJ/cm^2, giving FE thresholds as low as 30 V/μm. A typical image of the Nd:YAG laser processed PECVD a-Si:H is shown in Fig. 1.

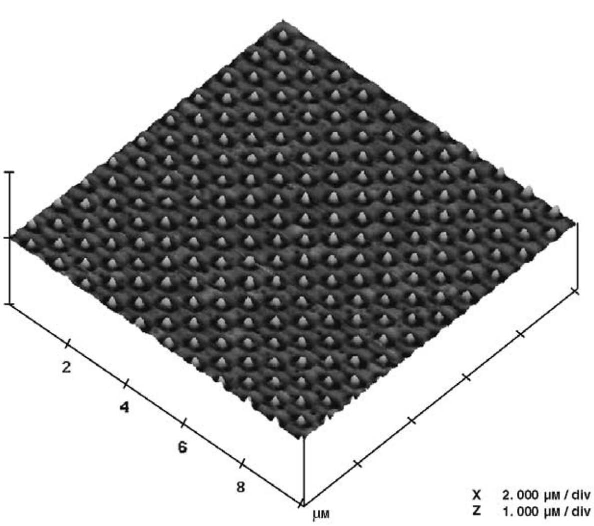

Fig. 1. A typical AFM image of PECVD a-Si:H, 100 nm, 100% SiH_4, irradiated with Nd:YAG laser at 140 mJ cm^{-2} to create periodic tip-like features. Thresholds fields for emission were approximately 30 V/μm.

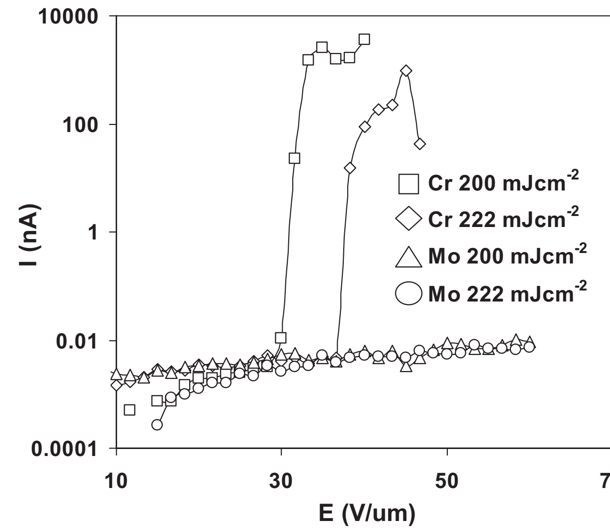

Fig. 2. Typical FE I–E plots for Cr and Mo backplane samples irradiated at 200 and 222 mJ cm^{-2}.

3.2. Excimer laser annealed HWCVD and PECVD

PECVD deposited 100nm a-Si:H films on molybdenum backplanes did not achieve any FE at H_2/SiH_4+H_2 ratios from 10% to 67%, up to fields of 60 V/μm. However, similar films deposited on chromium backplanes regularly produced stable currents in the nA to μA range at applied fields of between 25 to 50 V/μm. Especially for 200 and 222 mJ/cm^2 irradiation. Fig. 2 shows typical I–E curves. There is a major difference between the FE properties of the molybdenum and chromium back-planed films.

Upon closer inspection of the films it was discovered that the chromium films were cracked right through to the glass substrate-metal backplane interface. This was probably due to the rapid heating and cooling of the chromium backplane during ELA, a 'quenching' effect. This did not occur in the molybdenum backplane samples and is probably due to the difference in their thermal conductivity. Molybdenum's 139 W m^{-1} K^{-1} to chromium's 94 Wm^{-1} K^{-1}. AFM scans of the surfaces of the molybdenum and chromium samples showed similar roughness and feature geometry, hence comparable geometric field enhancement factors — taking the assumption that FE is attributed solely to FNT. However at the edges of the cracks, in the chromium backed films, high ridges were formed. The features are higher and sharper than anything present on the flat surface areas between the cracks or on the surface of the molybdenum samples. Fig. 3 shows these cracks. According to FNT these ridges, comprised of peaks, will have high geometric field