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Improvement of Electrical Characteristics of a-Si:H Thin Film Transistors by Hydrogen Plasma Back-Channel Ethcing Method

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In this article, we have investigated the electrical characteristics of hydrogen plasma etching on the back channel of thin film transistors in comparison with convention conventionally back-channel from $0.24\,cm^2/V\cdot s$ to $0.38\,cm^2/V\cdot s$. Back channel etch using hydrogen plasma makes it possible to obtain much better on-current characteristics than are obtained with conventional channel-etch by SF_6 plasma. At the same thickness of amorphous Si at 200 nm, field-effect mobility of thin film transistors using hydrogen plasma back channel etching is improved about 37% than using SF_6 plasma. The effects of the hydrogen plasma etching on the amorphous Si were checked using current-voltage plotter, atomic force microscopy and Fourier Transform Infrared spectrometry.

Keywords Back-channel etching; hydrogen plasma; TFT

Introduction

Most of amorphous silicon TFTs (thin film transistors) which are currently used are inverse-staggered type, and this structure can be made by two methods, which are back-channel etching and etch-stopper. The method using back-channel etching has some advantage in respect of processing cost, which is caused by less the number of photolithography process. In the other hand, it has some disadvantage which is caused by a degradation of "ON" characteristics, because n^+ a-Si:H layer must be over-etched. The degradation of "ON" characteristics can be compensated for by making the thickness of a-Si:H layer rather thick. Such a thick a-Si:H layer causes disadvantages, however, including high photosensitivity (i.e., an increase in "OFF" current under illumination), high series resistance in source/drain regions, and low throughput in the deposition and etching processes for the a-Si:H layer [1–4].

In this article, we used the hydrogen plasma for back-channel etching as one of the methods not to increase the thickness of a-Si:H layer. We measured the etching rate of n^+ a-Si:H layer in hydrogen plasma and fabricated TFTs by using hydrogen

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plasma. The effects of hydrogen plasma on the physical and chemical characteristics of etched back-channel were investigated by AFM (atomic force microscopy) and FT-IR (fourier transform infrared spectrometer), the effects of hydrogen plasma on the electrical characteristics of TFT were investigated by current-voltage plotter as well.

Experimental and Measurements

Figure 1 shows regular process flow chart of fabrication of TFTs in this experiments. We deposited and patterned a nichrome (NiCr) gate electrode on a glass substrate, and then a SiN_X gate insulator, an a-Si:H active layer, and a n^+ a-Si:H layer were consecutively deposited by PECVD (plasma enhanced chemical vapor deposition). The dry etching process was consecutively performed to pattern the a-SiN_x layer, the a-Si:H layer and the n^+ a-Si:H layer, and then aluminum (Al) is deposited and patterned as source/drain electrodes. Finally, back-channel was etched for the isolation of source and drain.

Nichrome was 150 nm as a gate electrode, and the thickness of a-SiN_X was fixed at 250 nm. The a-Si:H layer as a active layer was varied from 100 nm to 250 nm in order to observe variation of the effect of hydrogen plasma on the

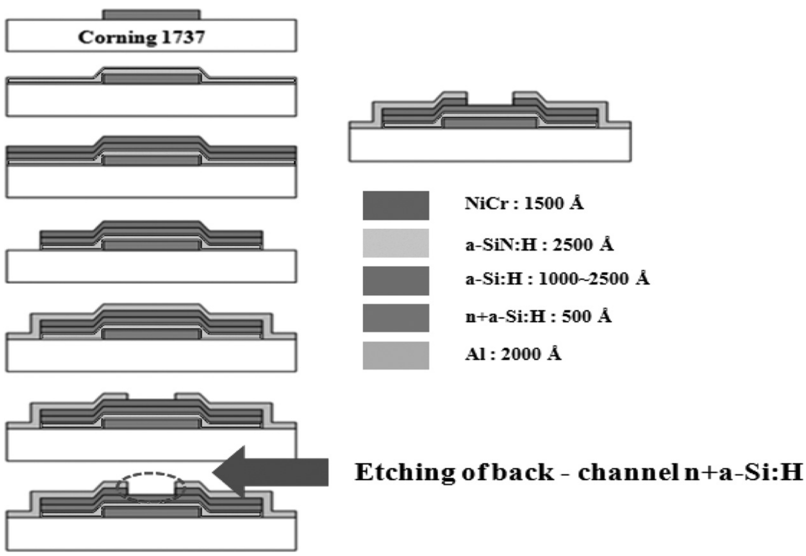

Figure 1. Process flow chart of inverted staggered a-Si:H TFTs.

Table 1. Etching conditions of back side n^+ a-Si:H

Parameter	Back channel side n^+ a-Si:H	
Gas	SF_6	SF_6
Flow rate (sccm)	20	20
r.f. power (W)	150	20
Substrate temperature (°C)	25	25
Working pressure (mTorr)	150	150
Etching time	18 min	14 sec

electrical characteristics of TFTs in accordance with gradually increasing the thickness of a-Si:H layer. The n^+ a-Si:H layer for ohmic contact with source/drain was 50 nm, and aluminum as a source/drain electrode was 200 nm. Back-channel etching was performed by two methods to compare hydrogen plasma with SF_6 plasma as conventional plasma etching gas. To find suitable power condition of

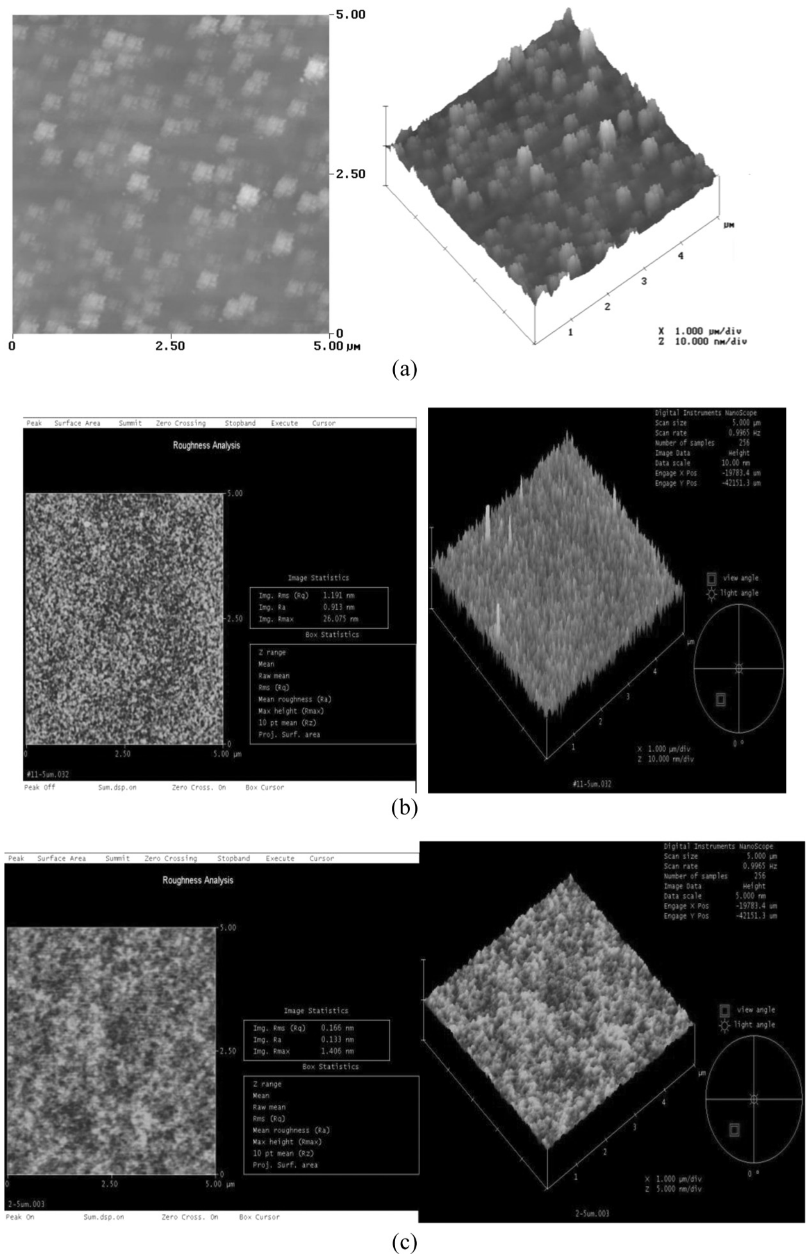

Figure 2. The results of AFM analysis on etched back-channel. (a) not etched back-channel, (b) etched back-channel by SF_6 plasma of 20 W, and (c) etched back-channel by hydrogen plasma of 40 W.

hydrogen plasma etching, plasma power were varied from 20 W to 80 W. Table 1 shows etching system and condition of back side n^+ a-Si:H.

Results and Discussion

Figure 2 shows the results of AFM analysis for back side n^+ a-Si:H. The Root-Mean-Square (RMS) roughness of (a) as not etched a-Si:H layer was 0.806 nm, (b) and (c) shows the RMS roughness of a-Si:H layers after n^+ a-Si:H are etched in SF_6 plasma of 20 W, and hydrogen plasma of 40 W, that were 1.129 nm, 0.166 nm respectively. The roughness of back-channel etched by SF_6 plasma was increased in comparison with not etched a-Si:H layer. On the contrary, the roughness of back-channel etched by hydrogen plasma was decreased than not etched one. Figure 3 shows a plot of the RMS roughness according to power condition of hydrogen plasma. The roughness of etched back-channel in hydrogen plasma at 20 W was higher value than the other conditions. Because etching condition at 20 W have to make a-Si:H layers exposed in the plasma for much longer time. The roughness at 40 W, 60 W and 80 W were 0.166 nm, 0.285 nm and 0.406 nm respectively. The RMS roughness at most power conditions except for 20 W were lower values than SF_6 plasma of 20 W.

Figure 4 shows the FT-IR results of a-Si:H layers according to a variation of etching condition. The hydrogen atomic contents of a-Si:H layers were calculated from Si-H bonding peak at 2000 cm^{-1} [5–7]. The hydrogen atomic contents of the case of (a) as not etched a-Si:H layer were 16.4 at.%, (b) and (c) shows hydrogen atomic contents after n^+ a-Si:H are etched in SF_6 plasma of 20 W, and hydrogen plasma of 40 W that were 15.3 at.%, 16.1 at.% respectively. The hydrogen atomic content of back-channel etched by SF_6 plasma was decreased in comparison with not etched a-Si:H layer. On the contrary, the hydrogen atomic contents of back-channel etched by hydrogen plasma was to not etched one.

Figure 5 shows electrical characteristics of thin film transistor according to a variation of etching condition. On/off current ratio was about 10^5 in most of etching conditions. And leakage current at off_state was about 1×10^{-11} A as shown (a).

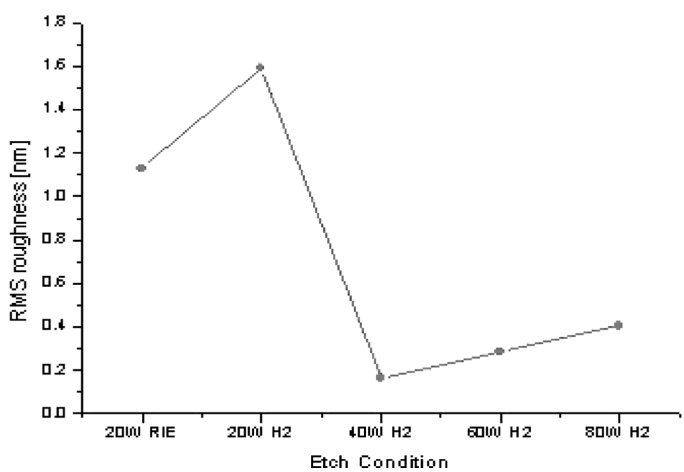

Figure 3. The roughness variation of a-Si:H with back-channel etching condition.

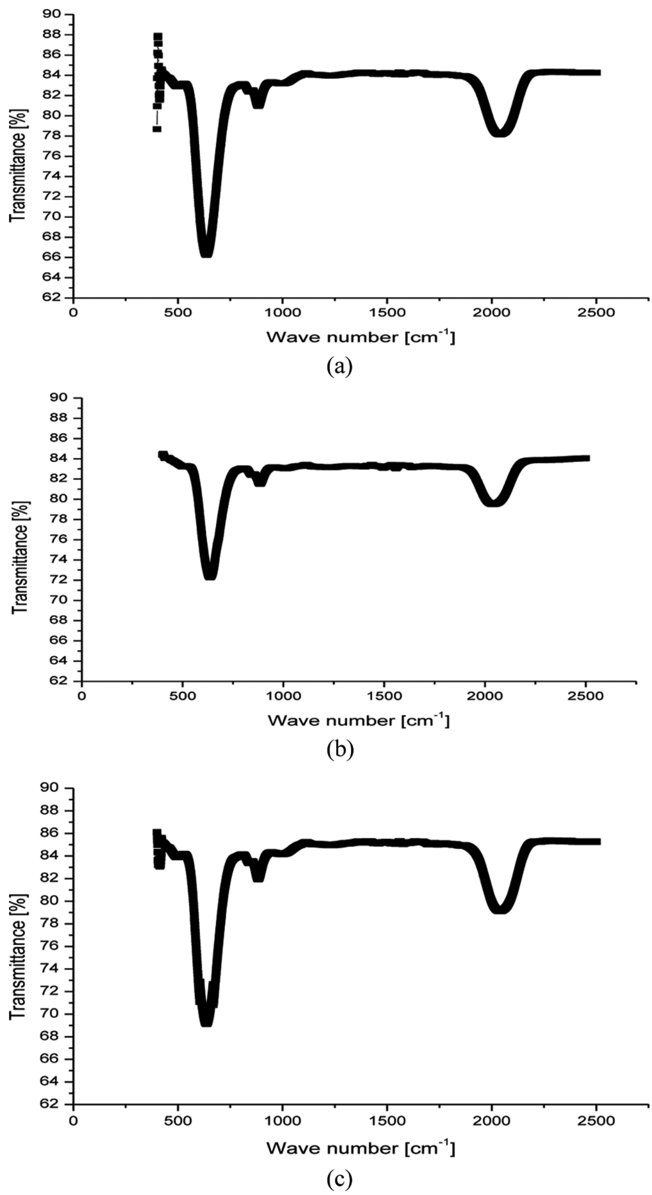

Figure 4. The FT-IR results of a-Si:H thin film for a variation of etching condition. (a) not etched back-channel, (b) etched back-channel by SF_6 plasma of 20 W, and (c) etched back-channel by hydrogen plasma of 20 W.

transfer characteristic for saturation region was shown at (b). it was measured at the state of VG=VD in order to calculate field effect mobility and threshold voltage.

Figure 6 shows field-effect mobility (μ_n) and threshold voltage (V_{th}) of TFTs according to the variation of the power condition in hydrogen plasma and SF_6 plasma of 20 W for back-channel etching, which were deduced from the saturated region by plotting the square root of the drain current against the gate voltage. Because output characteristics show good saturation and can be reasonably well

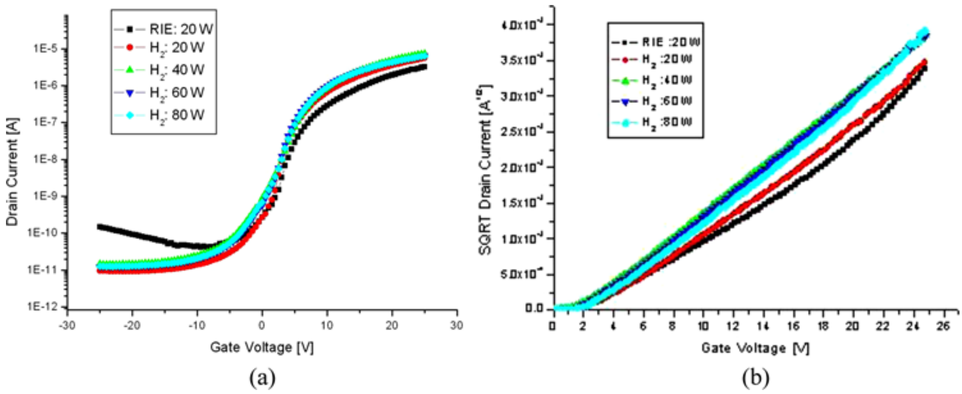

Figure 5. Electrical characteristics of thin film transistor according to the variation of back-channel etching condition. (a) on/off current ratio, and (b) transfer characteristic for saturation region.

described by the standard metal-oxide-semiconductor field effect transistor equations [8]. The field-effect mobility of TFTs using hydrogen plasma in the power condition of 20 W~80 W were generally higher value as $0.30\,cm^2/V\cdot s \sim 0.38\,cm^2/V\cdot s$ than using SF_6 plasma in the power condition of 20 W as $0.24\,cm^2/V\cdot s$. The threshold voltage of TFTs using hydrogen plasma in the power condition of 20 W, 40 W, 60 W and 80 W were 2.0 V, 1.3 V, 1.6 V and 1.8 V SF_6 plasma in the power condition of 20 W as 1.8 V. in case of using hydrogen plasma of 20 W, the threshold voltage of TFTs were 1.8 V.

In the same thickness of amorphous Si at 200 nm, field-effect mobility of thin film transistors using hydrogen plasma back channel etching is improved

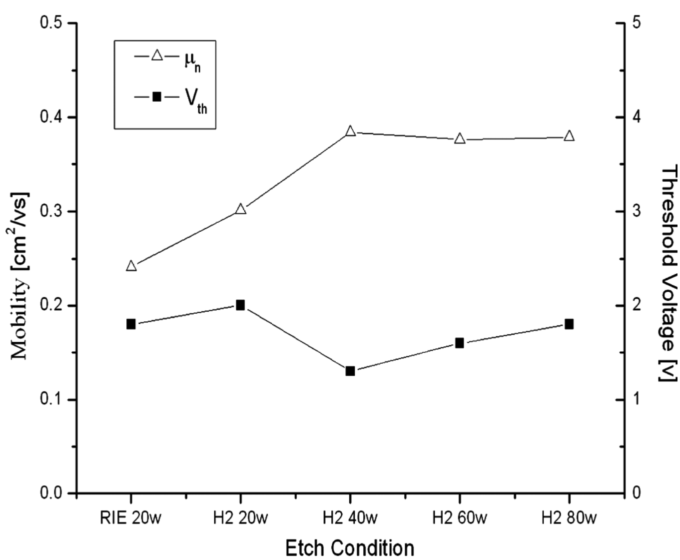

Figure 6. The mobility and threshold voltage shift for a variation of back-channel etching condition.

maximumly about 37% than using SF_6 plasma, which was caused by the increase of hydrogen contents at back channel. The hydrogen atoms prevent the dangling bond from building up and the a-Si:H layer has much lower density of states in the band gap than a general one [9–10].

Figure 7 shows the dependence on the a-Si:H thickness of threshold voltage (a) and field effect mobility (b) for both types of TFTs, respectively, which were extracted from transfer characteristic for saturation region. Threshold voltages for the case using SF_6 plasma etching were in the range of about 1.8 V$\sim$5.8 V for a-Si:H thicknesses ranging from 100 nm to 250 nm, and for the other using hydrogen plasma etching, threshold voltages were in the range of about 1.2 V$\sim$5.0 V for the same variation a-Si:H thicknesses. The field effect mobilities for back-channel etched

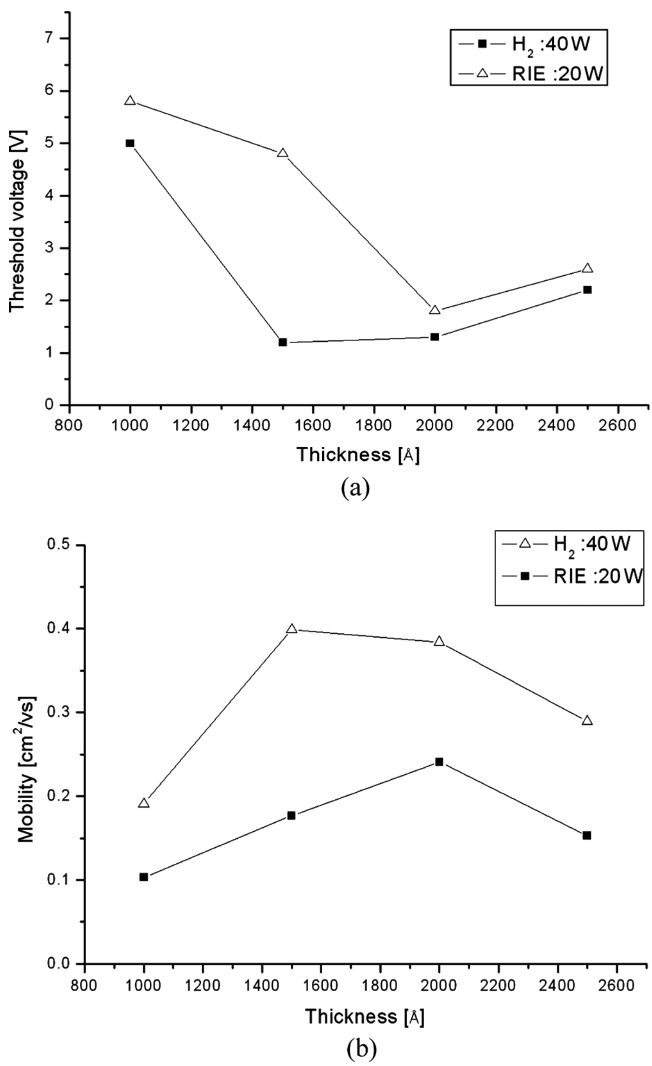

Figure 7. Characteristics variation of the thickness of the active layer. (a) threshold voltage, and (b) mobility.

TFT using SF_6 plasma decrease from $0.24\,cm^2/V \cdot s$ to $0.10\,cm^2/V \cdot s$ when the a-Si:H thickness decrease to 100 nm, whereas for the back-channel etched TFT using hydrogen plasma, they are in the range of $0.19\,cm^2/V \cdot s \sim 0.40\,cm^2/V \cdot s$ for the same variation for a-Si:H thicknesses.

We obtain the results that the "ON" current characteristics of TFT using hydrogen plasma for back-channel etching were superior to the case using SF_6 plasma when we were making a-Si:H thicknesses thinner.

Conclusions

In this article, we have found that hydrogen plasma etching for the process of source/drain isolation can be used, and "ON" current characteristics of TFT can be improved by using hydrogen plasma at the suitable condition instead of conventionally used SF_6 plasma. We have explained the effect of hydrogen plasma etching by measuring the variation of physical and chemical characteristics of a-Si:H layer as the active layer of TFT. Hydrogen bonds bring compensation for dangling bonds in a-Si:H layer, which are caused during back-channel etching process. We conclude that hydrogen plasma etching bring the effects of etching process and anneal process in the same time.

Acknowledgments

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References

[1] Kawushige Takechi, Naoto Hirano, Hiroshi Hayama, & Setsuo Kaneko. (1998). Back-channel-oxidized a-Si:H thin-film transistors. *J. Appl. Phys.*, *84*, 3993.
[2] Kang, S. G., Bae, S. C., & Choi, S. Y. (2000). The effect of back channel hydrogen plasma treatment on the electrical characteristics of amorphous thin film transistors. *Appl. Phys. Lett.*, *77*, 1188.
[3] Rosan, K. (1989). Hydrogenated amorphous-silicon image sensors. *IEEE, Electron Devices*, *36*(12), 2923–2927.
[4] Kagan, C. R., & Andry, P. (2003). *Thin-Film Transistors*, Marcel Dekker, Inc.
[5] Toshihisa Tsukada. (1996). *Liquid-Crystal Displays Addressed by Thin-Film Transistors*, Gordon and Breach Publishers, 103–124.
[6] Brodsky, M. H., Cardona, M., & Cuomo, J. J. (1977). Infrared and Raman spectra of the silicon-hydrogen bonds in amorphous silicon prepared by glow discharge and sputtering. *Physical Review B.*, *16*, 3356–3571.
[7] Lucovsky, G., Nemanich, R. J., & Knights, J. C. (1979). Structrual inter-pretation of the the vibrational spectra of a-Si:H alloys. *Physical Review B.*, *19*, 2064–2073.
[8] Jang, J. (2003). *Thin Films Transistors*, Marcel Dekker, Inc., 37–38.
[9] Morigaki, K. (1991). The correlation between photocreation of dangling bonds and Si-H bond clusters in a-Si:H. *Jpn. J. Appl. Phys.*, *29*, L1582–L1584.
[10] Hepburn, A. R., Marshall, J. M., Main, C., Powell, M. J., & van Berkel, C. (1986). *Phys. Rev. Lett.*, *56*, 2215.