square patch. The VSWR of the patch and its radiation patterns were measured with an HP8510B network analyser in an anechoic chamber with a reflectivity level of -25 dB. The results are shown in Figs. 2–4. The measured bandwidth is 3.11% (270 MHz, $f_o = 8.67$ GHz), 5.54% (540 MHz, $f_o = 9.75$ GHz) and 5.1% (600 MHz, $f_o = 11.76$ GHz) as shown in Fig. 2.

Many different centre frequencies of the filter were conceived and simulated. In general, the examination of diverse cases reveals that, as the centre frequency of the spur-line filter approaches the resonance frequency of the patch, the characteristics of the channel at the centre filter frequency improve,

Fig. 2 Measured VSWR of triple-band patch

Fig. 3 Measured radiation pattern of triple-band patch (H-plane)

Fig. 4 Measured radiation pattern of triple-band patch (E-plane)

which is envisioned due to the single feed point. On the other hand, a displacement of those centre frequencies is expected, which does not mean that they cannot be used, but it makes an accurate design laborious.

Conclusion: In summary, a novel triple-band microstrip antenna has been described. The new geometry of the microstrip patch antenna has proven to be a flexible and multiband element. This is particularly important for mobile communications systems where small size, light weight, low profile and low cost are often demanded in portable or pocket-size equipment and vehicles. It is especially relevant when a flush-mounted or built-in antenna is required.

Finally, it is appropriate to point out several lines along which further investigation could be carried out. Phased arrays based on the antenna could easily be designed and used in secondary surveillance, space-borne imaging or synthetic-aperture radar systems. Similarly a circularly polarised triple-band patch antenna could be very useful in applications such as global positioning system receivers, in a hand-held message-communication terminal (HMCT), or in satellite systems where at least two channels are needed to receive/transmit the telecommand and telemetry signals.

Acknowledgments: The authors wish to thank A. D. Lucas for his technical assistance. This work has been carried out under the sponsorship of CAM (Caja de Ahorros del Mediterráneo) and The British Council.

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5th July 1993

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ANALYTICAL DRAIN CURRENT MODEL FOR a-Si : H TFTs BY SIMULTANEOUSLY CONSIDERING LOCALISED DEEP AND TAIL STATES

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Indexing terms: Semiconductor device models, Thin film transistors

An analytical drain current model for a-Si : H TFTs obtained by considering deep and tail states simultaneously is presented. Using an effective temperature approach, the localised deep and tail states have been considered in the DC model such that no approximations are needed. As verified by the published data, this analytical DC model provides an accurate prediction on the drain current characteristics of an a-Si : H thin film transistor.

Introduction: Hydrogenated amorphous thin film transistors (a-Si : H TFTs) have been receiving much attention recently owing to their on-chip integration capabilities with complex arrays of a-Si : H LCDs [1] and other image-sensing arrays [2]. To facilitate circuit design for a-Si : H digital control circuits, effective device models for a-Si : H TFTs are important [3].

Owing to the complicated distribution of localised acceptor states in the energy gap of amorphous silicon as shown in Fig. 1a, analytical models of the free and trapped charges in the channel of the a-Si : H TFT are difficult to obtain. By neglecting either one of the deep states and the tail states, simplified analytical drain current models for a-Si : H TFTs have been obtained [4]. For this approach, as the band bending in the electrostatic potential is large, the density of the localised acceptor states predicted may not be acceptable. In addition, for the simplified model, the assumption that the density of the localised acceptor states is much greater than the density of free carriers also limits its applicability.

In this Letter, using an 'effective temperature', both deep and tail states can be included in deriving the analytical model without simplification. It will be shown in the following that the analytical model provides an accurate prediction of the drain current characteristics of an a-Si : H TFT.

Fig. 1 Cross-section of typical a-Si : H thin film transistor and distribution of localised acceptor states in the energy gap of amorphous silicon

- a Cross-section of a-Si : H transistor
b Distribution of localised acceptor states

Model derivation: Consider a typical a-Si : H TFT as shown in Fig. 1b. Using a simplified Fermi-Dirac distribution and applying the Poisson equation in the a-Si : H TFT with the relationship: $2(d\Psi/dx)(d^2\Psi/dx^2) = (d/dx)(d\Psi/dx)^2$, the electric field of a function for the electrostatic potential in the a-Si : H TFT has been obtained:

$$E(\Psi) = \sqrt{\frac{2}{\epsilon} \left(kT_d n_A e^{(q\Psi - E_{fo})/kT_d} + kT_n n_B e^{(q\Psi - E_{fo})/kT_n} + kT_c n_c e^{(q\Psi - E_{fo})/kT_c} \right)} \quad (1)$$

$$n_A = g_d kT - \frac{g_d}{\left(\frac{1}{kT} + \frac{1}{kT_d}\right)} + \frac{g_d}{\left(\frac{1}{kT} - \frac{1}{kT_d}\right)}$$

$$n_B = g_t kT_i - \frac{g_t}{\left(\frac{1}{kT_i} + \frac{1}{kT}\right)} - \frac{g_t}{\left(\frac{1}{kT_i} - \frac{1}{kT}\right)}$$

$$n_C = g_d \frac{1}{\left(\frac{1}{kT_d} - \frac{1}{kT}\right)} + g_t \frac{1}{\left(\frac{1}{kT_i} - \frac{1}{kT}\right)} + N_c$$

where g_d and g_t are the deep state density and the tail state density at the conduction band edge, respectively. T_d and T_t are the characteristic temperatures of the deep states and tail states, respectively. k is the Boltzmann constant. ϵ is the permittivity of the a-Si. T is the temperature in Kelvin. N_c is the effective density of states in the a-Si.

Defining an 'effective temperature' as

$$T_{ef}(\Psi) = \frac{q\Psi - E_{fo}}{k \ln \frac{E(\Psi)}{A}} \quad (2)$$

$$A = \sqrt{\frac{2}{\epsilon} (kT_d n_A + kT_t n_B + kT_c n_C)}$$

and integrating the free carrier density in the vertical direction of the a-Si : H TFT from the oxide/a-Si interface ($x = 0$) to the end of the channel in the a-Si thin film ($x = t$), the total number of free carriers in the a-Si : H TFT has been obtained:

$$N_{free} = \int_0^t N_c e^{(q\Psi - E_{fo})/kT} dx \quad (3)$$

where E_{fo} is the difference between E_c and the Fermi level in the bulk. From the Gauss law, the total charges in the a-Si : H TFT, which include the localised trapped charges and the free electrons can be related to the electric field at the oxide/a-Si interface as

$$N_{free} + N_{loc} = \frac{\epsilon}{q} E(\Psi_s) \quad (4)$$

where Ψ_s is the electrical potential at oxide/a-Si interface. Fig. 2 shows the total charge in localised states (N_{loc}) and total free

Fig. 2 Total charge in localised states (N_{loc}) and total free carriers (N_{free}) in an a-Si : H TFT as a function of band bending in the electrostatic potential at the oxide/amorphous interface (Ψ_s) based on the analytical model and the numerical simulation result [9]

— our model

● Shur et al., numerical result [13]

carriers (N_{free}) in an a-Si : H TFT as a function of band bending in the electrostatic potential at the oxide/amorphous interface based on the analytical model and the numerical simulation result [5]. As shown in the Figure, the analytical model derived from the effective temperature shows a close fit to the published results. In fact, using the effective temperature approach, the assumptions that $n_{loc} \gg n_{free}$ and the separate consideration of the deep states and tail states as required in other analytical models [6] are no longer needed in deriving the n_{free} formula. Applying the Gauss law at the oxide/a-Si interface and considering the voltage drop in the oxide region, the electrostatic potential at oxide/a-Si interface has been found as a function of the gate voltage. Using the Ohm law and gradual channel approximation, the drain current of an a-Si : H TFT biased with a drain voltage V_d and a gate voltage

of V_g , is expressed as

$$I_D = \frac{W}{L} \mu_o \frac{N_c}{A \left[\frac{1}{kT} - \frac{1}{T_{ef}(\Psi_s)} \right]} \left(\frac{C_{ox}}{\epsilon A} \right)^{(T_{ef}(\Psi_s)/T - 1)} \frac{T}{T_{ef}(\Psi_s)} \times \left[(V_g - V_{fb})^{T_{ef}(\Psi_s)/T} - (V_g - V_{fb} - V_d)^{T_{ef}(\Psi_s)/T} \right] \quad (5)$$

where μ_o is the band mobility, W is the channel width, L is the channel length, C_{ox} is the unit area oxide capacitance and V_{fb} is the flat-band voltage.

Comparison with experimental data: To verify the analytical drain model using the effective temperature approach, an a-Si:H TFT with a channel length of $8 \mu\text{m}$ and a channel width $80 \mu\text{m}$ has been used in the study. The a-Si:H TFT has an a-Si thin film of $500 \text{ \AA}$ and a gate oxide of $3000 \text{ \AA}$. The band mobility μ_o is $17 \text{ cm}^2/\text{vs}$. The effective density of states N_c is $7 \times 10^{19} \text{ cm}^{-3}$. Fig. 3 shows the drain current characteristics of the a-Si:H TFT based on the analytical model using the effective temperature approach and the published data [7]. A close fit between the model results and the published data can be observed. From the analytical model derived in the preceding Sections, the differences between the a-Si:H TFT and single-crystalline MOSFET come from the trapped charges. If no trapped charges exist ($g_d = 0$, $g_t = 0$), the analytical a-Si:H TFT model becomes the typical formula as for single-crystalline MOSFETs.

Fig. 3 Drain current characteristics of the a-Si:H TFT transistor under study based on the analytical model and the published data

— our model
● measured data [17]

Conclusion: An analytical drain current model for a-Si:H TFTs by considering deep and tail states simultaneously has been reported. Using an effective temperature approach, the localised deep and tail states have been considered in the DC model such that no approximations are needed. As verified by the published data, this analytical DC model provides an accurate prediction of the drain current characteristics of an a-Si thin film transistor.

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7th July 1993

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BANDWIDTH LIMITS DUE TO POLARISATION MULTIPLEXED SOLITON INTERACTIONS

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Indexing terms: Optical transmission, Optical communication, Soliton transmission

The Letter reveals the bandwidth limits that result from the interactions between orthogonally polarised solitons in an optical fibre transmission link with time and polarisation division multiplexing.

Introduction: The use of polarisation/time division multiplexing has been recently proposed and demonstrated in a long distance soliton transmission experiment [1]. It was observed that for orthogonally polarised adjacent solitons, pulse to pulse interactions are much weaker than for solitons with identical polarisation (in the following called the scalar case) [1, 2]. This means that the temporal separation between two adjacent and orthogonal solitons may be reduced with respect to the scalar case. As a result, the polarisation multiplexing technique may permit an increase of the maximum transmission bandwidth of soliton transmission systems.

The extent of this bandwidth increase due to polarisation multiplexing has not yet been determined. In this work we present a numerical and perturbative analysis of polarisation multiplexed soliton interactions. We reveal an unexpected discrepancy between two different perturbation approaches.

Theory: The nonlinear propagation of the u polarisation component of a pulse in a long distance fibre link may be described, in dimensionless soliton units, by the perturbed nonlinear Schrödinger (NLS) equation [1, 3]

$$iu_z + \frac{1}{2}u_{TT} + |u|^2u = -\varepsilon|v|^2u \quad (1)$$

The equation for the orthogonal component v is obtained from eqn. 1 by interchanging u and v . In the presence of random birefringence, averaging over all soliton polarisation states [1, 3] leads to the integrable vector NLS equation with $\varepsilon = 1$ [4]. We numerically solved eqn. 1 with $\varepsilon = 1$ and

$$u, v(T, Z = 0) = \text{sech}(T \pm \Delta/2) \quad (2)$$

Fig. 1 shows the evolution of the intensities in the two polarisation components of the field against distance Z : here $\Delta = 6$.

Fig. 1 Intensities in u, v polarisations with $\Delta = 6$, and input of eqn. 2