UNIVERSITI SAINS MALAYSIA

First Semester Examination
Academic Session 2011/2012

Januari 2012

EBB 424/3 – Semiconductor Devices and Optoelectronic
[Peranti Semikonduktor dan Optoelektronik]

Duration : 3 hours
[Masa : 3 jam]

Please ensure that this examination paper contains FOURTEEN printed pages before you begin the examination.
[Sila pastikan bahawa kertas peperiksaan ini mengandungi EMPAT BELAS muka surat yang bercetak sebelum anda memulakan peperiksaan ini.]

This paper consists of ONE question from PART A, THREE questions from PART B and THREE questions from PART C.
[Kertas soalan ini mengandungi SATU soalan dari BAHAGIAN A, TIGA soalan dari BAHAGIAN B dan TIGA soalan dari BAHAGIAN C.]

Instruction: Answer **ONE** question from PART A, **TWO** questions from PART B and **TWO** questions from PART C. If candidate answers more than five questions only the first five questions answered in the answer script would be examined.
*[**Arahan**: Jawab **SATU** soalan dari BAHAGIAN A, **DUA** soalan dari BAHAGIAN B dan **DUA** soalan dari BAHAGIAN C. Jika calon menjawab lebih daripada lima soalan hanya lima soalan pertama mengikut susunan dalam skrip jawapan akan diberi markah.]*

The answers to all questions must start on a new page.
[Mulakan jawapan anda untuk semua soalan pada muka surat yang baru.]

You may answer a question either in Bahasa Malaysia or in English.
[Anda dibenarkan menjawab soalan sama ada dalam Bahasa Malaysia atau Bahasa Inggeris.]

In the event of any discrepancies, the English version shall be used.
[Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah diguna pakai.]

PART A:

BAHAGIAN A:

1. [a] Consider a symmetry *n*-channel of (JFET) shown in Figure 1. The width of each depletion region is extending into the *n*-channel is *W*. The thickness, or depth, of the channel, defined between the two metallurgical junctions, is 2*a*. Assuming that it is an abrupt *pn* junction and V_{DS} = 0. Calculate the pinch-off voltage of a JFET that has an acceptor concentration of 10^{19} cm^{-3} in the p^+ gate, a channel donor doping of 10^{16} cm^{-3}, and a channel thickness (depth), 2*a*, of 2μm.

Anggapkan satu simetri "n-channel of (JFET)" yang ditunjukkan dalam Rajah 1. Lebar untuk setiap kawasan penyusutan diteruskan sehingga ke kawasan "n-channel" ialah W. Tebal atau kedalaman untuk "channel" ditakrifkan sebagai 2a, iaitu jarak antara dua "metallurgical junctions". Anggapkan ia adalah satu "abrupt pn junction" dan V_{DS} = 0. Kirakan voltan "pinch-off" untuk JFET tersebut dengan kepekatan penerima 10^{19} cm^{-3} di get p^+, kepekatan pemberi di "channel" ialah 10^{16} cm^{-3}, dan ketebalan "channel", 2a, ialah 2μm.

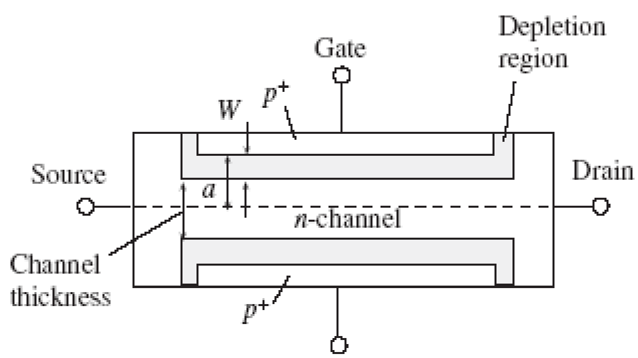

Figure 1: A symmetric n-channel JFET

Rajah 1: Satu simetri n-channel JFET

(50 marks/*markah*)

[b] Figure 2 shows a correlation between bandgap energy and lattice constant of semiconductor materials. Suggest semiconductor materials that can be used to emit light with energy of 1.5 eV. Of the materials you suggested state which would be suitable to be grown on substrates (e.g. Si, GaAs or InP)?

Rajah 2 menunjukkan hubungkait antara jurang tenaga dan pemalar kekisi bahan semikonduktor. Cadangkan bahan semikonduktor yang dapat digunakan untuk menghasilkan cahaya bertenaga 1.5 eV. Di antara bahan-bahan yang dipilih, nyatakan adakah yang sesuai dengan substrat yang sedia ada (misalnya Si, GaAs atau InP)?

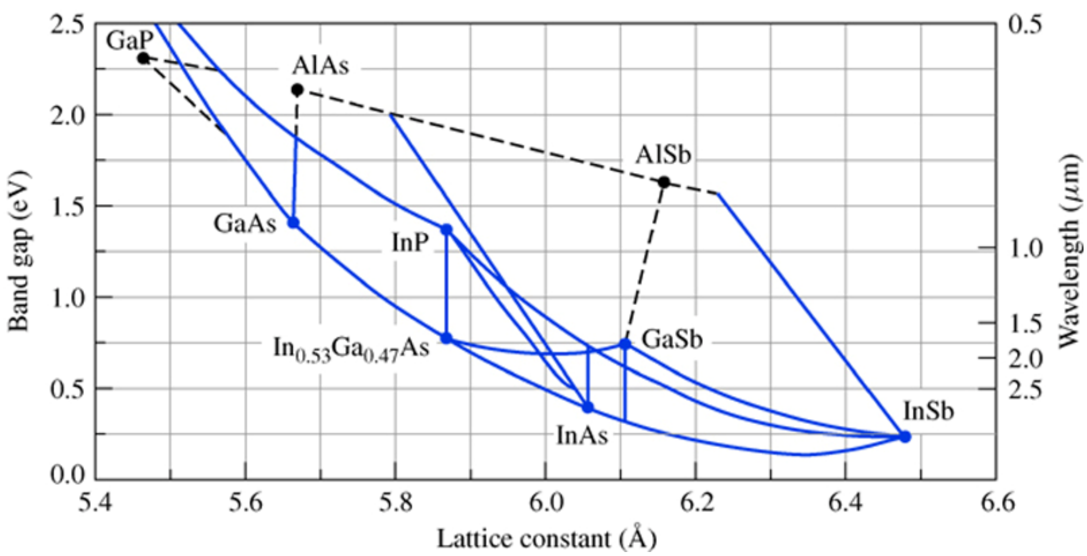

Figure 2: Correlation between bandgap energy and lattice constant of semiconductor materials

Rajah 2: Hubungkait antara jurang tenaga dan pemalar kekisi bahan semikonduktor.

(50 marks/*markah*)

PART B:

BAHAGIAN B:

2. [a] Reverse current (I_{rev}) in a *pn* junction is represented by:

$$\frac{\delta I_{rev}}{I_{rev}} \approx \left(\frac{E_g}{\eta kT}\right)\frac{\delta T}{T}$$

where k is Boltzmann's constant, T is temperature, and η = 2 for Si and GaAs, in which thermal generation in the depletion layer dominates the reverse current, and η = 1 for Ge, in which the reverse current is due to minority carrier diffusion to the depletion layer. It is assumed that $E_g >> kT$ at room temperature. Order the semiconductors Ge, Si, and GaAs according to the sensitivity of the reverse current to temperature by providing strong justifications.

Arus terbalik (I_{rev}) di dalam satu "simpang pn" diwakili oleh:

$$\frac{\delta I_{rev}}{I_{rev}} \approx \left(\frac{E_g}{\eta kT}\right)\frac{\delta T}{T}$$

di mana k ialah pemalar Boltzmann, T ialah suhu, dan η = 2 untuk Si dan GaAs, di mana generasi terma di dalam lapisan penyusutan dikuasai oleh arus terbalik, dan η = 1 untuk Ge, di mana arus terbalik disebabkan oleh difusi penggerak minoriti di dalam lapisan penyusutan. Ia dianggapkan $E_g >> kT$ pada suhu bilik. Susunkan bahan semikonduktor Ge, Si, dan GaAs mengikut kepekaan terhadap arus terbalik mengikut suhu dengan memberi jawapan anda dengan justifikasi yang kuat.

(30 marks/*markah*)

[b] What are the technological and material parameters that influence a forward-biased *pn* junction? Briefly explain your answers.

Apakah teknologi dan parameter-parameter bahan yang mempengaruhi "simpang pn berpincang hadapan"? Terangkan jawapan anda.

(20 marks/*markah*)

[c] Consider a forward-biased *pn* junction carrying a *constant* current *I*. Change in the voltage across the *pn* junction per unit change in the temperature is given by:

$$\frac{dV}{dT} = -\left(\frac{V_g - V}{T}\right)$$

where $V_g = E_g/e$ is the energy gap expressed in volts. Calculate typical values for dV/dT for Ge, Si and GaAs assuming that, typically, V = 0.2 V for Ge, 0.6 V for Si, and 0.9 V for GaAs. What is your conclusion?

Anggapkan satu "simpang pn berpincang hadapan" membawa arus yang malar I. Penukaran voltan merentasi "simpang pn" per unit pertukaran suhu ialah seperti berikut:

$$\frac{dV}{dT} = -\left(\frac{V_g - V}{T}\right)$$

di mana $V_g = E_g/e$ ialah jurang tenaga dalam unit volt. Kirakan nilai-nilai yang lazim dV/dT untuk Ge, Si dan GaAs, anggapkan, V = 0.2 V untuk Ge, 0.6 V untuk Si, dan 0.9 V untuk GaAs. Apakah rumusan yang anda boleh lakukan?

(30 marks/*markah*)

[d] Briefly explain the differences between Avalanche and Zener breakdown.

Terangkan secara ringkas perbezaan di antara "Avalanche" dan "Zener breakdown".

(20 marks/*markah*)

3. [a] With the help of energy band diagrams, explain the differences between an enhancement of NFET and depletion of NFET.

Dengan bantuan gambarajah jalur tenaga, terangkan perbezaan di antara satu "enhancement NFET" dan "NFET tersusut".

(30 marks/*markah*)

[b] A particular MOSFET process produces $C_B^{'}$ =10^{-7}F/cm^2 and I_0 = 4 x 10^{-20} A a threshold voltage of V_T=0.5V. For gate oxide thicknesses of 6.5 nm and 4 nm, find *n* and *S*. Which device is better, and why?

Satu proses MOSFET menghasilkan $C_B^{'}=10^{-7} F/cm^2$ *dan* $I_0 = 4 \times 10^{-20} A$, *dan voltan "threshold",* V_T*=0.5V. Untuk oksida get dengan tebal 6.5 nm dan 4 nm, kira nilai n dan S. Peranti manakah yang lebih baik dan berikan sebab anda?*

(40 marks/*markah*)

[c] Figure 3 shows the I_D-V_{GS} characteristic for an NMOS with V_{DS}=50 mV. It is known for this device that *W*=10μm, *L*=0.5μm, and t_{ox}=5 nm.

(i) Find the threshold voltage.

Rajah 3 menunjukkan ciri I_D-V_{GS} *untuk NMOS dengan* V_{DS}*=50 mV. Untuk peranti ini W=10μm, L=0.5μm, dan* t_{ox}*=5 nm.*

(i) Dapatkan voltan "threshold"

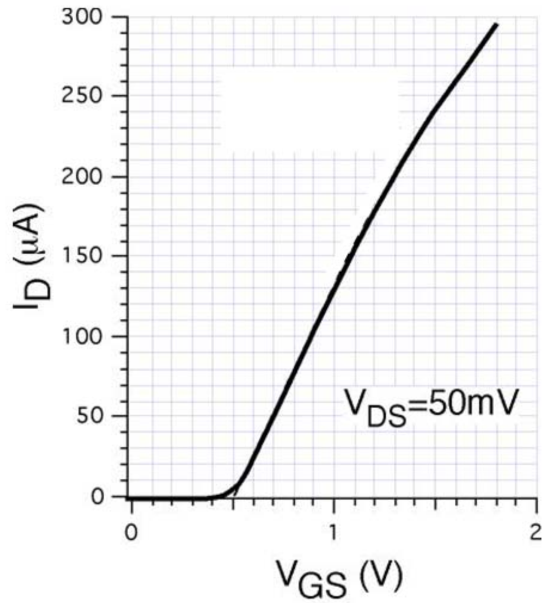

Figure 3: $I_D - V_{GS}$ characteristic of an NMOS

Rajah 3: Ciri-ciri $I_D - V_{GS}$ bagi NMOS

(ii) Find μ_0, the electron channel mobility at threshold.

Dapatkan μ_0, "kelincahan 'channel' elektron" pada nilai "ambang" tersebut.

(30 marks/*markah*)

4. [a] With the help of energy band and block charge diagrams, explain the differences between an N-type MOS capacitor under accumulation, flatband, depletion, inversion, and deep-depletion modes.

Dengan bantuan gambarajah-gambarajah jalur tenaga dan cas blok, terangkan perbezaan di antara kapasitor MOS jenis-N dalam keadaan "accumulation", "flatband", "depletion", "inversion", dan "deep-depletion".

(50 marks/*markah*)

[b] A gate voltage V_G = 5 V is applied to the MOS capacitor shown in Figure 4. If the threshold voltage V_{Tn} of this structure is less than 5 Volts determine the following:

Satu voltan get V_G = 5 V dibekalkan ke kapasitor MOS seperti yang ditunjukkan dalam Rajah 4. Sekiranya voltan "threshold" V_{Tn} struktur ini adalah kurang daripada 5 Volt, tentukan berikut:

(Assume that the relative permitivities of SiO_2 and Silicon are respectively 4 and 12, and ε_0 =8.854 x 10^{-14} F/cm, n_i = 1.5 x 10^{10}/cm^3, V_T = 25 mV.)

(Anggapkan permitiviti relatif untuk SiO_2 dan Si ialah 4 dan 12, dan ε_0 =8.854 x 10^{-14} F/cm, n_i = 1.5 x 10^{10}/cm^3, V_T = 25 mV.)

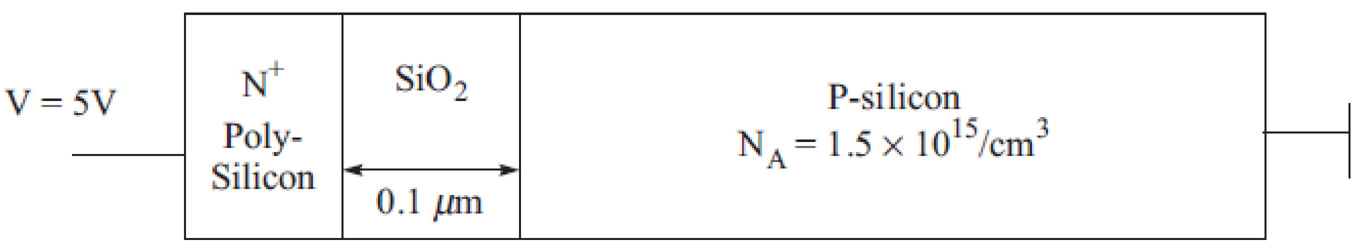

Figure 4: A cross-sectional view of a MOS capacitor

Rajah 4: Keratan rentas suatu kapasitor MOS

(i) Voltage across the oxide.

Voltan merentasi oksida.

(10 marks/*markah*)

(ii) The electric field at the surface of silicon.

"Medan elektrik" pada permukaan silikon.

(10 marks/*markah*)

(iii) Inversion layer charge/cm^2.

Lapisan "terbalik" dalam unit cas/cm^2.

(15 marks/*markah*)

(iv) High frequency capacitance/cm^2.

Gelombang tinggi dalam unit kapasitan/cm^2.

(15 marks/*markah*)

PART C:

BAHAGIAN C:

5. [a] The absorption coefficient in amorphous silicon is approximately 10^{14} cm^{-1} at photon energy of 1.7 eV and 10^{5} cm^{-1} at 2.0 eV. Determine the amorphous silicon thickness for each case so that 90% of the photons are absorbed.

Pekali penyerapan silikon amorfus ialah lebih kurang 10^{14} cm^{-1} pada tenaga foton 1.7 eV dan 10^{5} cm^{-1} pada 2.0 eV. Tentukan ketebalan silikon amorfus bagi setiap kes untuk mampu menyerap 90% foton.

(30 marks/*markah*)

[b] The refractive index at wavelength, λ= 800 nm of AlGaAs photodiode is 3.65. If the junction depth is 0.3 μm, and the junction width is 1.5 μm, find the quantum efficiency (η_Q) and the responsivity (R_{ph}). Assume the light is incident from air and the absorption coefficient of AlGaAs at 800 nm is $\alpha = 9 \times 10^{3}$ cm^{-1}.

Indeks biasan fotodiod AlGaAs pada panjang gelombang λ= 800 nm ialah 3.65. Jika kedalaman simpang ialah 0.3 μm, dan lebar simpang 1.5 μm, tentukan kecekapan kuantum (η_Q) dan kebersambutan (R_{ph}). Anggap sinar tuju dari udara dan pekali penyerapan AlGaAs pada 800 nm ialah $\alpha = 9 \times 10^{3}$ cm^{-1}.

(50 marks/*markah*)

[c] Discuss the advantages of p-i-n and avalance photodiodes compared to the simple pn junction photodiode.

Bincang kebaikan fotodiod p-i-n dan runtuhan dibandingkan dengan fotodiod mudah simpang pn.

(20 marks/*markah*)

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6. [a] Define short-circuit current and open-circuit voltage in a pn junction solar cell.

Berikan takrifan "short-circuit current" dan "open-circuit voltage" dalam satu sel suria simpang pn.

(20 marks/*markah*)

[b] Figure 5 shows a typical *I-V* characteristic of a solar cell. Determine the short-circuit current (I_{sc}), open-circuit voltage (V_{oc}), and calculate efficiency (η). The incident power is 20 mW.

Rajah 5 menunjukkan ciri I-V lazim bagi sel suria. Tentukan arus litar-pintas (I_{sc}), voltan litar-terbuka (V_{oc}), dan kira kecekapan (η). Kuasa tuju ialah 20 mW.

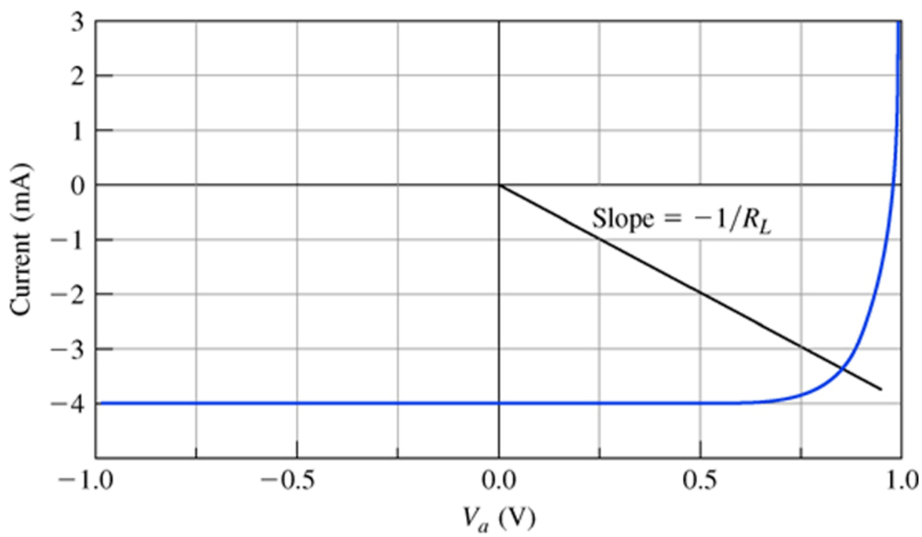

Figure 5: A typical *I-V* characteristic of a solar cell

Rajah 5: Ciri I-V lazim bagi sel suria.

(40 marks/*markah*)

[c] Figure 6 shows a solar spectrum irradiance at air mass 0 and 1 (AM0 and AM1). Based on the bandgap value of given materials, choose and explain two (2) the most promising materials for solar energy conversion application. Given bandgap value of Ge = 0.78 eV, Si = 1.17 eV, InP = 1.35 eV, GaAs = 1.42 eV, GaP = 3.30 eV, ZnO = 3.40 eV, and ZnS = 3.6 eV.

Rajah 6 menunjukkan spektrum sinaran suria pada jisim udara 0 dan 1 (AM0 dan AM1). Dengan merujuk kepada nilai jurang jalur bahan yang diberikan, pilih dan jelaskan dua (2) bahan yang paling sesuai untuk kegunaan penukaran tenaga suria. Diberikan nilai jurang jalur bagi Ge = 0.78 eV, Si = 1.17 eV, InP = 1.35 eV, GaAs = 1.42 eV, GaP = 3.30 eV, ZnO = 3.40 eV, dan ZnS = 3.6 eV.

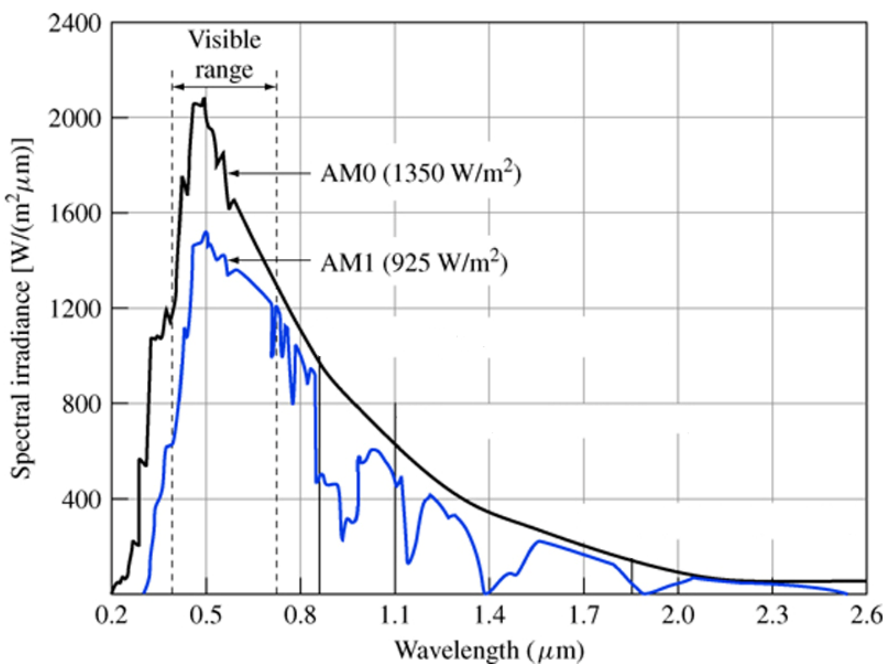

Figure 6: Solar spectrum irradiance at air mass 0 (AM0) and 1 (AM1)

Rajah 6: Spektrum penyinaran suria pada jisim udara 0 (AM0) dan 1 (AM1)

(40 marks/*markah*)

7. [a] Consider an n-type silicon photodetector with a length L = 50 μm, cross-sectional area $A = 10^{-7}$ cm^2, and minority lifetime $\tau_p = 10^{-6}$ s. If applied voltage V = 10 volts, calculate the photoconductor gain of the device.

Pertimbangkan suatu fotopengesan silikon dengan panjang L = 50 μm, keluasan keratan rentas $A = 10^{-7}$ cm^2, dan masa hayat minoriti $\tau_p = 10^{-6}$ s. Jika voltan dikenakan V = 10 volt, kira kedapatan pengaliran bagi peranti tersebut.

(20 marks/*markah*)

[b] Discuss the concept of stimulated emission in a semiconductor laser diode.

Bincangkan gagasan pancaran terangsang dalam laser diod semikonduktor.

(30 marks/*markah*)

[c] Consider an optical cavity laser. If integer $N >> 1$ and length of the cavity is L, show that the wavelength separation between two adjacent resonant modes is $\Delta\lambda = \lambda^2/2L$.

Pertimbangkan suatu rongga optik laser. Jika integer N >> 1 dan panjang rongga ialah L, tunjukkan bahawa panjang gelombang pemisahan antara dua mod resonan berhampiran ialah. $\Delta\lambda = \lambda^2/2L$.

(30 marks/*markah*)

[d] If the photon output of the laser diode is equal to the bandgap energy, find the wavelength sparation between adjacent resonant modes in a GaAs laser with length of the cavity L = 75 μm. Given bandgap energy GaAs = 1.42 eV.

Jika output foton laser diod ialah sama dengan tenaga jurang, tentukan panjang gelombang pemisahan antara dua mod resonan berhampiran dalam laser GaAs dengan panjang rongga L = 75 μm. Diberikan jurang tenaga bagi GaAs = 1.42 eV.

(20 marks/*markah*)

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