Medan Elektromagnetik

W6

Dielektrik dan Bagian-bagiannya

Reza Diharja, S.Si., M.T. | Prodi Teknik Elektro | Universitas Jayabaya

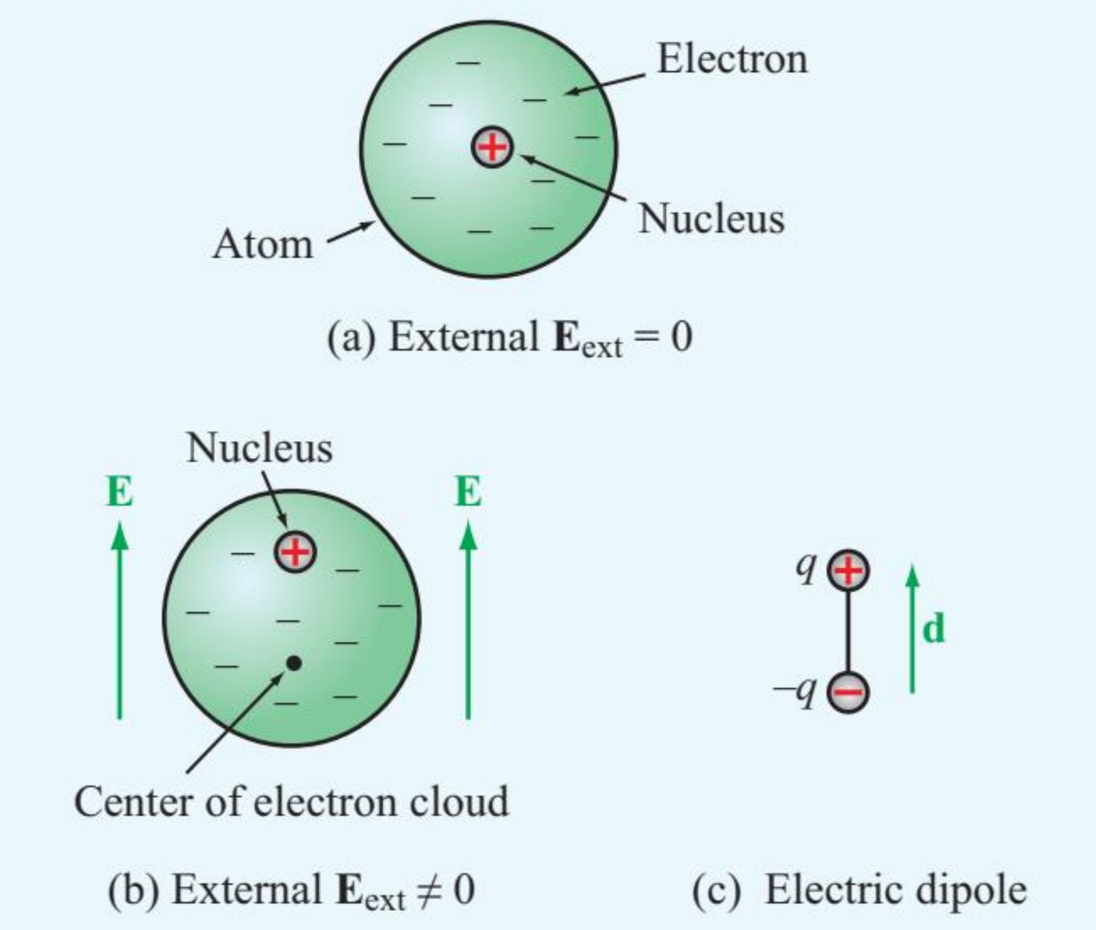
Outline Presentasi

6 Dielektrik

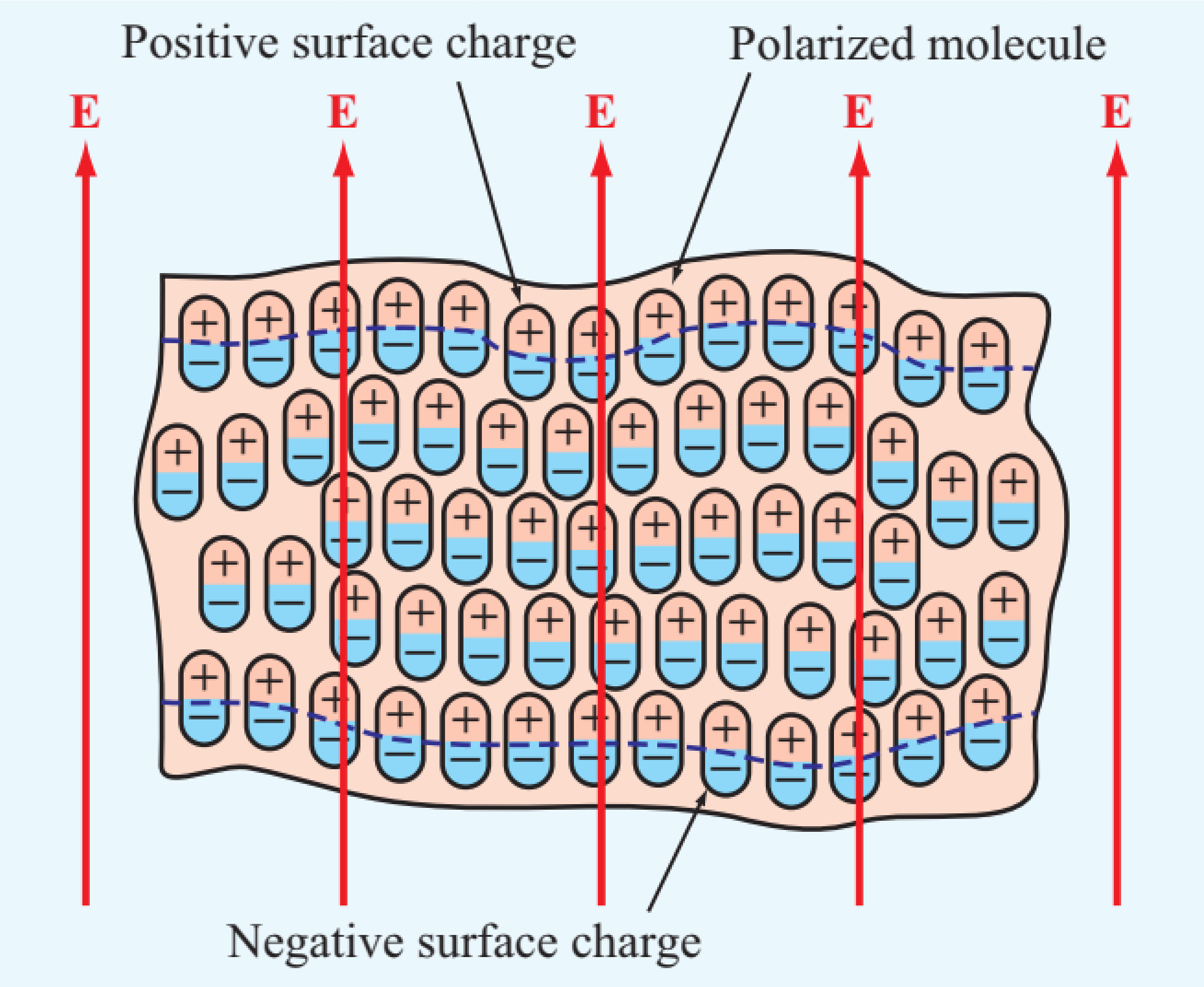
- 6.1 Medan Terpolarisasi
- 6.2 Dielectric Breakdown
- 6.3 Syarat Batas Listrik (*Electric Boundary Conditions*)

Dielektrik

Dasar utama perbedaan antara konduktor dan dielektrik adalah **elektron-elektron pada kulit terluar atom konduktor tertaut buruk terhadap atom** sehingga dapat dengan **bebas berpindah melewati material**, sedangkan pada dielektrik, kebalikannya.



Gambar 6.1 Tanpa hadirnya medan listrik eksternal **E**, pusat awan elektron (non-polar) berada sama dengan pusat nukleus, namun ketika terdapat medan listrik, maka dua pusat tersebut terpisah dengan jarak *d* (terinduksi-*polarized*).



Gambar 6.2 Medium dielektrik terpolarisasi oleh medan listrik eksternal **E**

In polar materials such as water, the molecules possess built-in ***permanent dipole moments*** that are randomly oriented in the absence of an applied electric field, and owing to their random orientations, the dipoles of polar materials produce no net macroscopic dipole moment (at the macroscopic scale, each point in the material represents a small volume containing thousands of molecules). Under the influence of an applied field, the permanent dipoles tend to align themselves along the direction of the electric field in a manner similar to that shown in **Fig. 4-19** for nonpolar materials.

Tabel 6.1 Permitivitas relatif (konstanta dielektrik) dan Kuat dielektrik dari berbagai macam material

Material	Relative Permittivity, ε_r	Dielectric Strength, E_{ds} (MV/m)
Air (at sea level)	1.0006	3
Petroleum oil	2.1	12
Polystyrene	2.6	20
Glass	4.5–10	25–40
Quartz	3.8–5	30
Bakelite	5	20
Mica	5.4–6	200

Note: $\varepsilon = \varepsilon_r \varepsilon_0$ and $\varepsilon_0 = 8.854 \times 10^{-12}$ F/m.

Medan Terpolarisasi

Pada *free space*, nilai $\mathbf{D} = \varepsilon_0 \mathbf{E}$, kehadiran dipol mikroskopik pada material dielektrik memunculkan :

$$\mathbf{D} = \varepsilon_0 \mathbf{E} + \mathbf{P} \qquad (6.1)$$

Untuk medium tertentu, nilai **P** proporsional dengan **E**:

$$\mathbf{P} = \varepsilon_0 \chi_\mathrm{e} \mathbf{E} \qquad (6.2)$$

Maka menjadi:

$$\mathbf{D} = \varepsilon_0 \mathbf{E} + \varepsilon_0 \chi_\mathrm{e} \mathbf{E} = \varepsilon_0 (1 + \chi_\mathrm{e}) \mathbf{E} = \varepsilon \mathbf{E} \qquad (6.3)$$

The polarization field is produced by the electric field E and depends on the material properties.

A dielectric medium is said to be linear if the magnitude of the induced polarization field P is directly proportional to the magnitude of E, and isotropic if P and E are in the same. direction
In such anisotropic dielectrics, E and P may have different directions. A medium is said to be homogeneous

P adalah medan listrik terpolarisasi
χ_e adalah suseptibilitas listrik dari suatu material

$\varepsilon = \varepsilon_0 (1 + \chi_\mathrm{e})$ adalah definisi dari permitivitas listrik

Dielectric Breakdown

Model polarisasi dielektrik mengaitkan bahwa nilai medan listrik **E** tidak melewati nilai kritisnya, ini disebut dengan **Kuat Dielektrik** E_{ds}

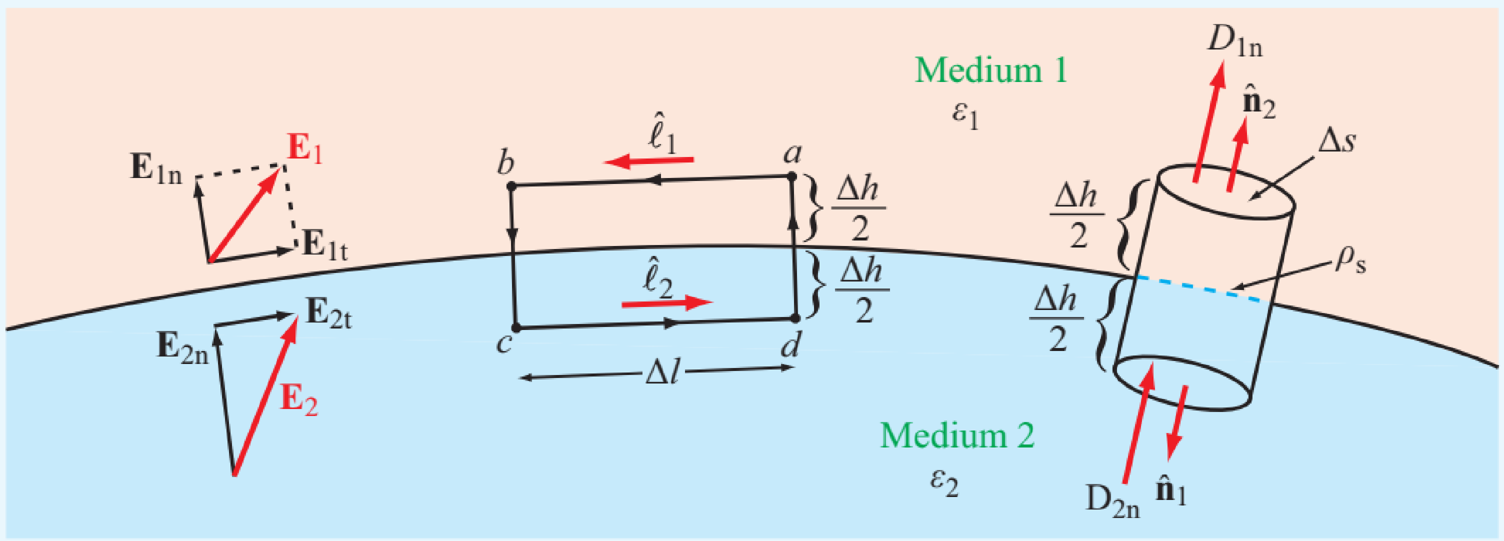
Sebaliknya, jika melewati nilai kritisnya, elektron akan terpisah dari molekul dan mengalami percepatan karena arus listrik, memunculkan bunga api, maka **material dielektrik mengalami kerusakan akibat tumbukan elektron dengan struktur molekul**. Kejadian ini disebut dengan ***dielectric breakdown***

The dielectric strength E_{ds} *is the largest magnitude of E that the material can sustain without breakdown.*

A charged thundercloud at electric potential V relative to the ground induces an electric field $E = V/d$ in the air beneath it, where d is the height of the cloud base above the ground. If V is sufficiently large so that E exceeds the dielectric strength of air, ionization occurs and a lightning discharge follows.

Syarat Batas Listrik (*Electric Boundary Conditions*)

- Even though the electric field may be continuous in adjoining dissimilar media, it may well be discontinuous at the boundary between them.
- Boundary conditions specify how the components of fields tangential and normal to an interface between two media relate across the interface.
- Derive a general set of boundary conditions for **E, D,** and **J** that is applicable at the interface between any two dissimilar media—be they two dielectrics or a conductor and a dielectric.
- Gambar 6.3 shows an interface between medium 1 with permittivity ε_1 and medium 2 with permittivity ε_2. In the general case, the interface may contain a surface charge density ρ_s (unrelated to the dielectric polarization charge density).

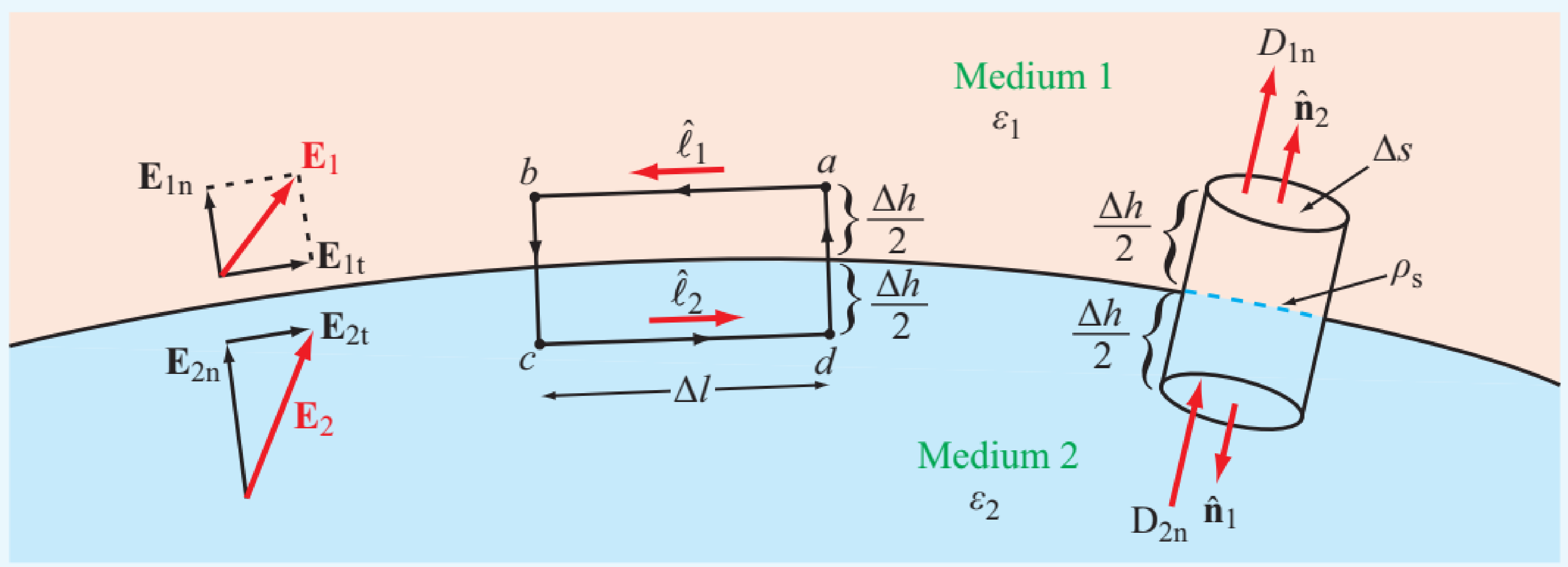


Gambar 6.3 Antarmuka diantara dua medium dielektrik

- Untuk menurunkan syarat batas pada komponen tangensial **E** dan **D**, andaikan terdapat loop rectangular tertutup abcda (Gambar 6.3) dan menerapkan sifat hukum kekekalan medan listrik.
- Menyatakan bahwa integral garis pada medan elektrostatik di sekitar lintasan tertutup akan selalu nol. Dengan memberikan $\Delta h \longrightarrow 0$, kontribusi integral garis pada segmen bc dan da menjadi hilang.

$$\oint_C \mathbf{E} \cdot d\mathbf{l} = \int_a^b \mathbf{E}_1 \cdot \hat{l}_1 \, dl + \int_c^d \mathbf{E}_2 \cdot \hat{l}_2 \, dl = 0 \qquad (6.4)$$

▶ A vector field is said to be ***spatially continuous*** if it does not exhibit abrupt changes in either magnitude or direction as a function of position. ◀



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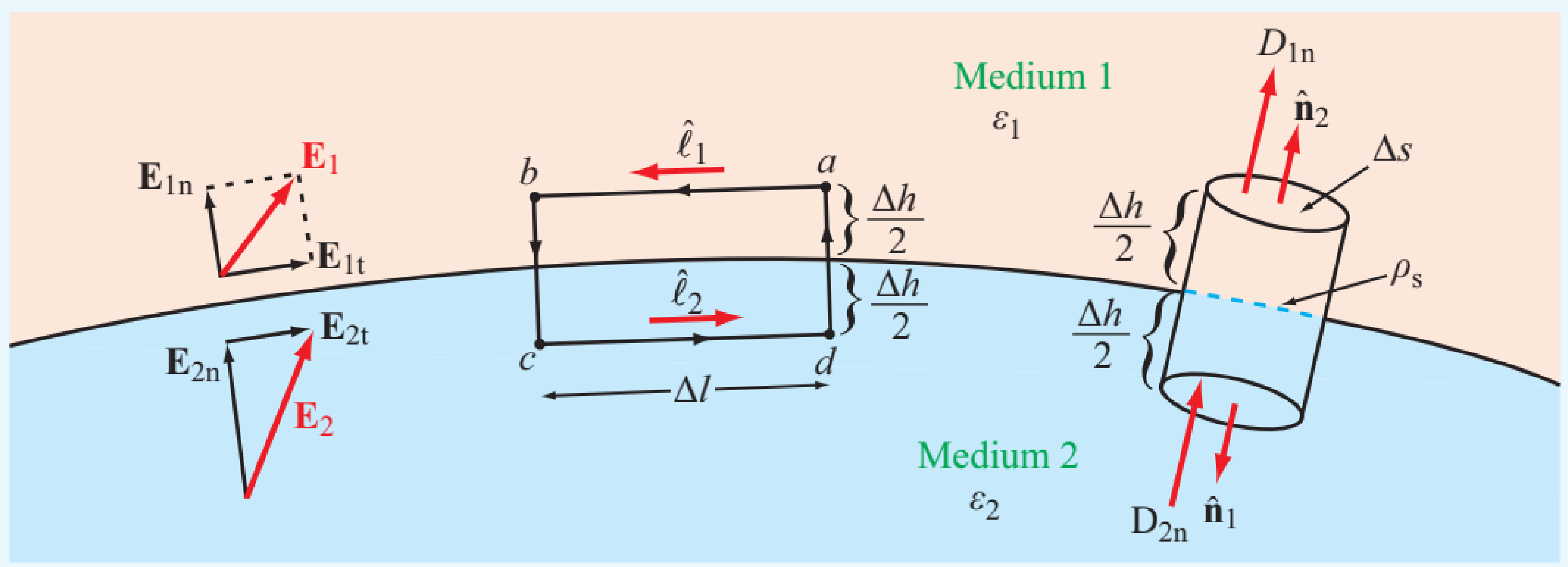
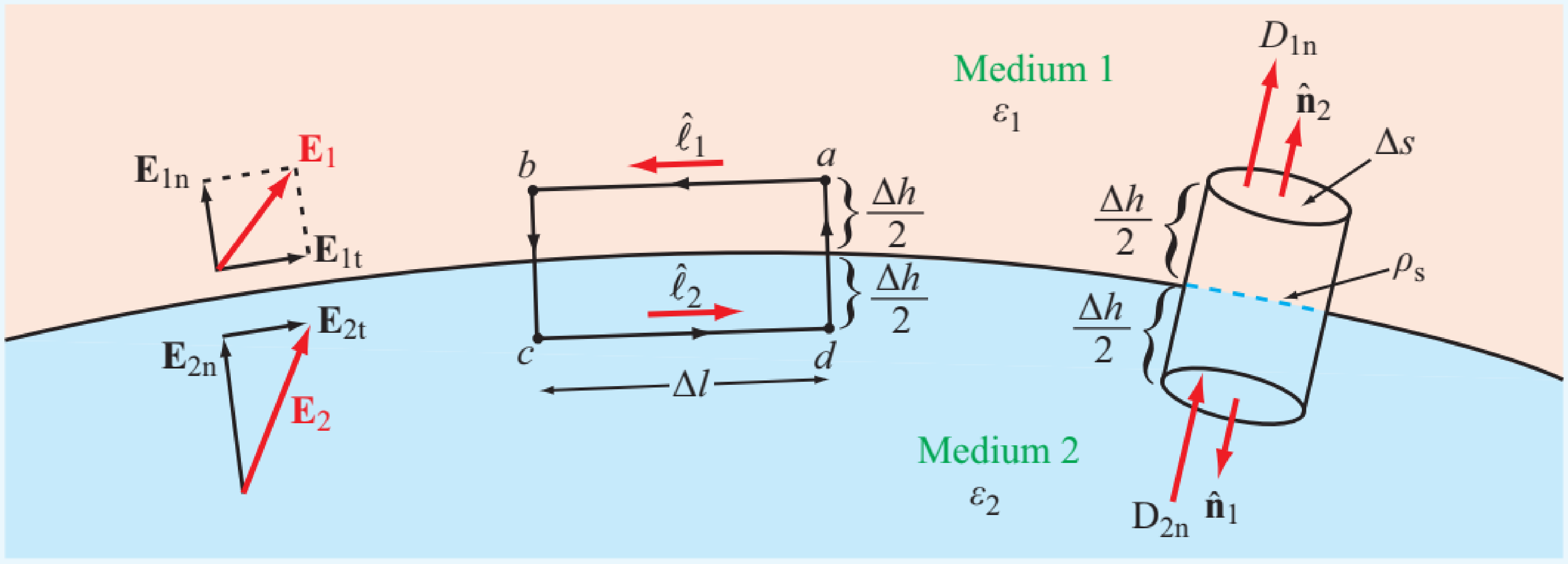




Dekomposisi $\mathbf{E}_1$ dan $\mathbf{E}_2$ menjadi komponen tangensial dan normal terhadap batas:

$$\mathbf{E}_1 = \mathbf{E}_{1t} + \mathbf{E}_{1n} \tag{6.5a}$$

$$\mathbf{E}_2 = \mathbf{E}_{2t} + \mathbf{E}_{2n} \tag{6.5b}$$

$$\hat{l}_1 = -\hat{l}_2$$

$$(\mathbf{E}_1 - \mathbf{E}_2) \cdot \hat{l}_1 = 0 \tag{6.6}$$

Komponen $\mathbf{E}_1$ sepanjang $\hat{l}_1$ sama dengan $\mathbf{E}_2$ sepanjang $\hat{l}_1$, untuk semua $\hat{l}_1$, tangensial terhadap batas, maka:

$$\mathbf{E}_{1t} = \mathbf{E}_{2t} \qquad \text{V/m} \tag{6.7}$$

► Thus, the tangential component of the electric field is **continuous** across the boundary between any two media. ◄

Kesimpulannya,

Untuk sifat konservatif dari medan listrik **E**

$$\nabla \times \mathbf{E} = 0 \iff \oint_C \mathbf{E} \cdot d\mathbf{l}$$

Membawa kepada hasil E memiliki komponen tangensial kontinyu yang melewati batas dan sifat divergensi pada **D**

$$\nabla \cdot \mathbf{D} = \rho_\mathrm{v} \iff \oint_S \mathbf{D} \cdot d\mathbf{s} = Q$$

Membawa kepada hasil bahwa komponen normal **D** akan berubah karena ρ_s yang melewati batas.

Tabel 6.2 Syarat batas untuk medan listrik

Field Component	Any Two Media	Medium 1 Dielectric ε_1	Medium 2 Conductor
Tangential E	$\mathbf{E}_{1t} = \mathbf{E}_{2t}$	$\mathbf{E}_{1t} = \mathbf{E}_{2t} = 0$	
Tangential D	$\mathbf{D}_{1t}/\varepsilon_1 = \mathbf{D}_{2t}/\varepsilon_2$	$\mathbf{D}_{1t} = \mathbf{D}_{2t} = 0$	
Normal E	$\varepsilon_1 E_{1n} - \varepsilon_2 E_{2n} = \rho_s$	$E_{1n} = \rho_s/\varepsilon_1$	$E_{2n} = 0$
Normal D	$D_{1n} - D_{2n} = \rho_s$	$D_{1n} = \rho_s$	$D_{2n} = 0$

Notes: (1) ρ_s is the surface charge density at the boundary; (2) normal components of $\mathbf{E}_1$, $\mathbf{D}_1$, $\mathbf{E}_2$, and $\mathbf{D}_2$ are along $\hat{\mathbf{n}}_2$, which is the outward normal unit vector of medium 2.

Contoh

Humidity Sensor

Thin-film metal electrodes shaped in an ***interdigitized pattern*** (to enhance the ratio A/d) are fabricated on a silicon substrate (**Fig. TF9-2**). The spacing between digits is typically on the order of $0.2\ \mu\text{m}$. *The effective permittivity of the material separating the electrodes varies with the relative humidity of the surrounding environment.* Hence, the capacitor becomes a humidity sensor.

in the direction of the lower plate. Consequently, d_1 increases and d_2 decreases, and in turn, C_1 decreases and C_2 increases (**Fig. TF9-3(c)**). The converse happens when $P < P_0$. With the use of a capacitance bridge circuit, such as the one in **Fig. TF9-1(b)**, the sensor can be calibrated to measure the pressure P with good precision.

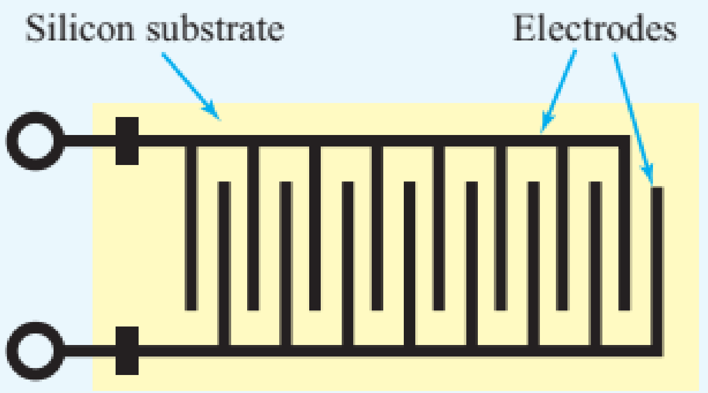
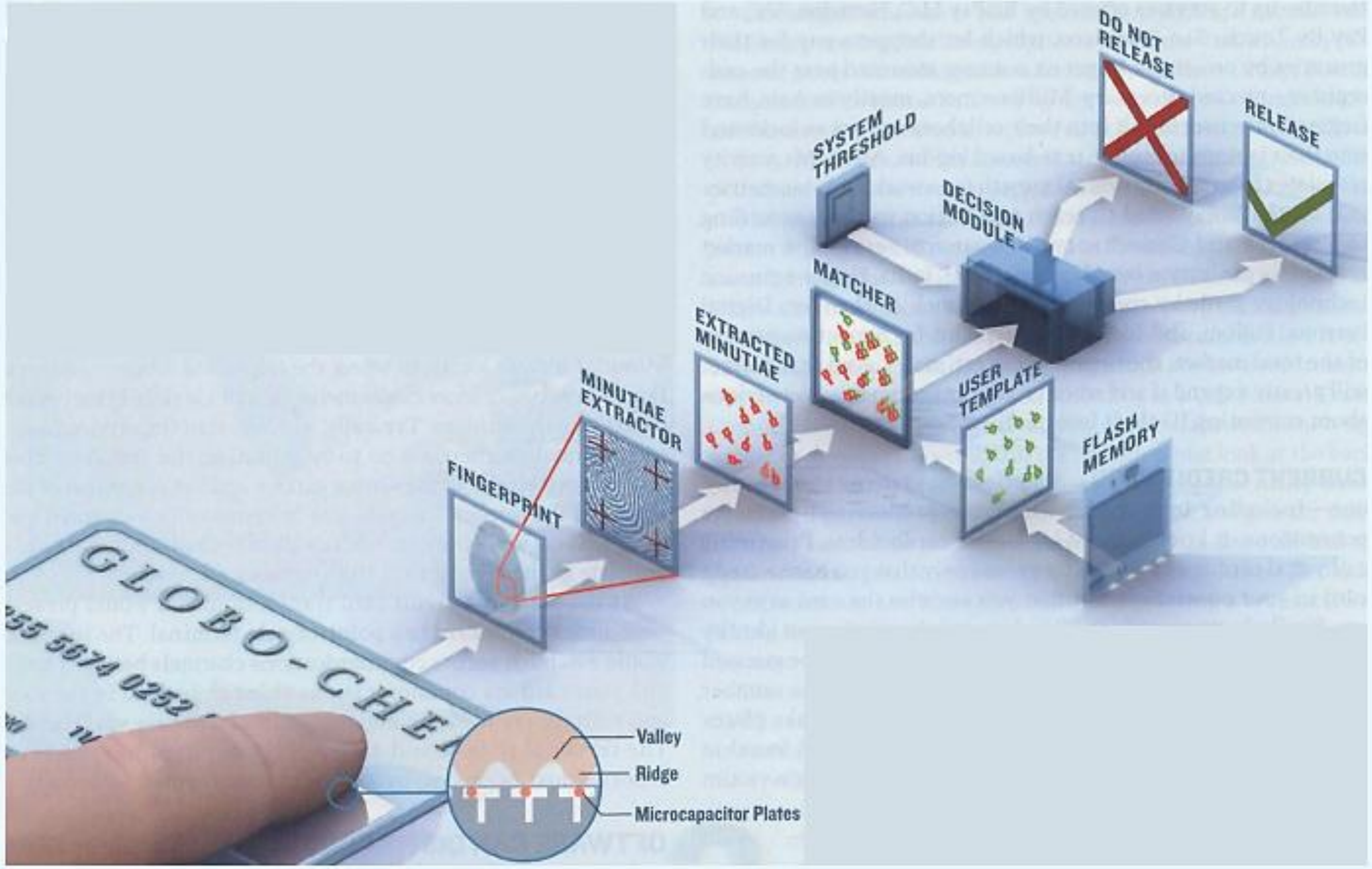


Figure TF9-2 Interdigital capacitor used as a humidity sensor.

Fingerprint Imager

An interesting extension of noncontact capacitive sensors is the development of a fingerprint imager consisting of a two-dimensional array of capacitive sensor cells constructed to record an electrical representation of a fingerprint (**Fig. TF9-6**). Each sensor cell is composed of an adjacent-plates capacitor connected to a capacitance measurement circuit (**Fig. TF9-7**). The entire surface of the imager is covered by a thin layer of nonconductive oxide. When the finger is placed on the oxide surface, it perturbs the field lines of the individual sensor cells to varying degrees, depending on the distance between the ridges and valleys of the finger's surface from the sensor cells.



► Given that the dimensions of an individual sensor are on the order of 65 μm on the side, the imager is capable of recording a fingerprint image at a resolution corresponding to 400 dots per inch or better. ◄