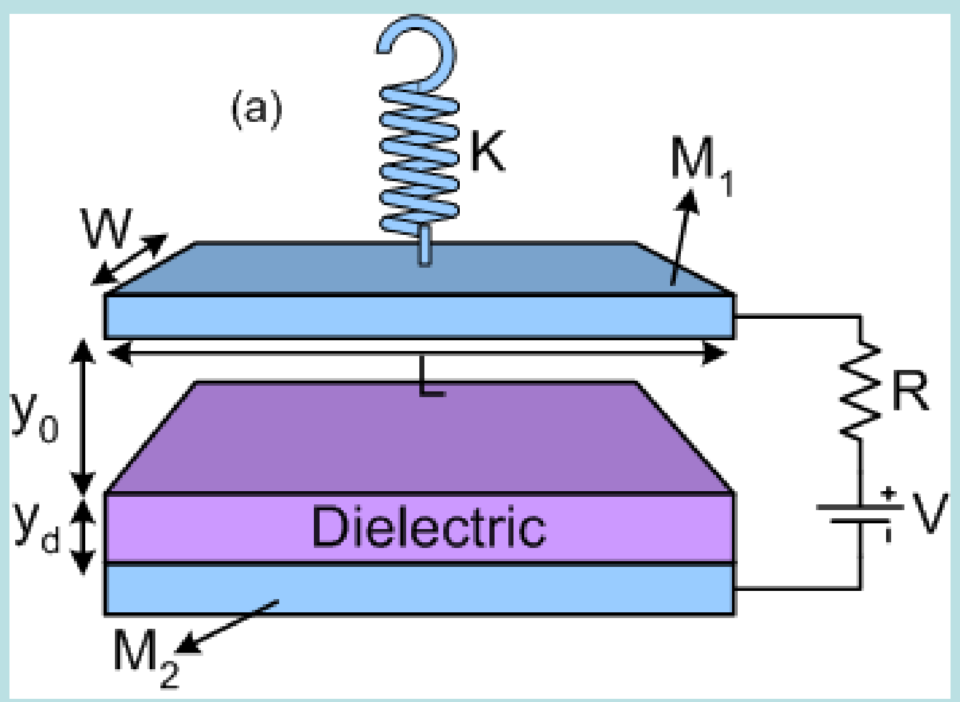
Strategies for dynamic Soft-Landing in Capacitive MicroElectroMechanical Switches

Ankit Jain, Sambit Palit and Muhammad A. Alam – Dept of ECE, Purdue University

PRISM
NNSA Center for Prediction of Reliability, Integrity and Survivability of Microsystems

RF-MEMS Capacitive Switch



Equation of Motion:

$$m\frac{d^2y}{dt^2} = k(y_0 - y) - \frac{0.5\varepsilon_0\varepsilon_r^2 WLV^2}{(y_d + \varepsilon_r y)^2}$$

Multiple Reliability Challenges in RF-MEMS

✓ **Dielectric Charging**
- ❖ **Charges are injected into the dielectric**
- ❖ **Causes pull-in/pull-out voltage to change**
- ❖ **Lead to failure due to stiction**

✓ **Creep**
- ❖ **Causes membrane to move down**
- ❖ **Capacitance keeps on increasing**

➢ **Surface Degradation**
- ❖ **Caused by impact velocity**
- ❖ **Energy dissipation at the surface**
- ❖ **Lead to failure due to stiction**

Soft Landing

➢ **Technique to reduce surface degradation by reducing impact velocity**

➢ **Traditional techniques**
- ❖**Closed loop requires feedback of position or velocity (Not possible for an ensemble of switches)**
- ❖**Open loop use input waveform shaping (requires additional circuitry and sensitive to process variation)**

➢ **Proposed Techniques**
- ❖**Resistive Braking**
- ❖**Capacitive Braking**

Dynamics of the Switch

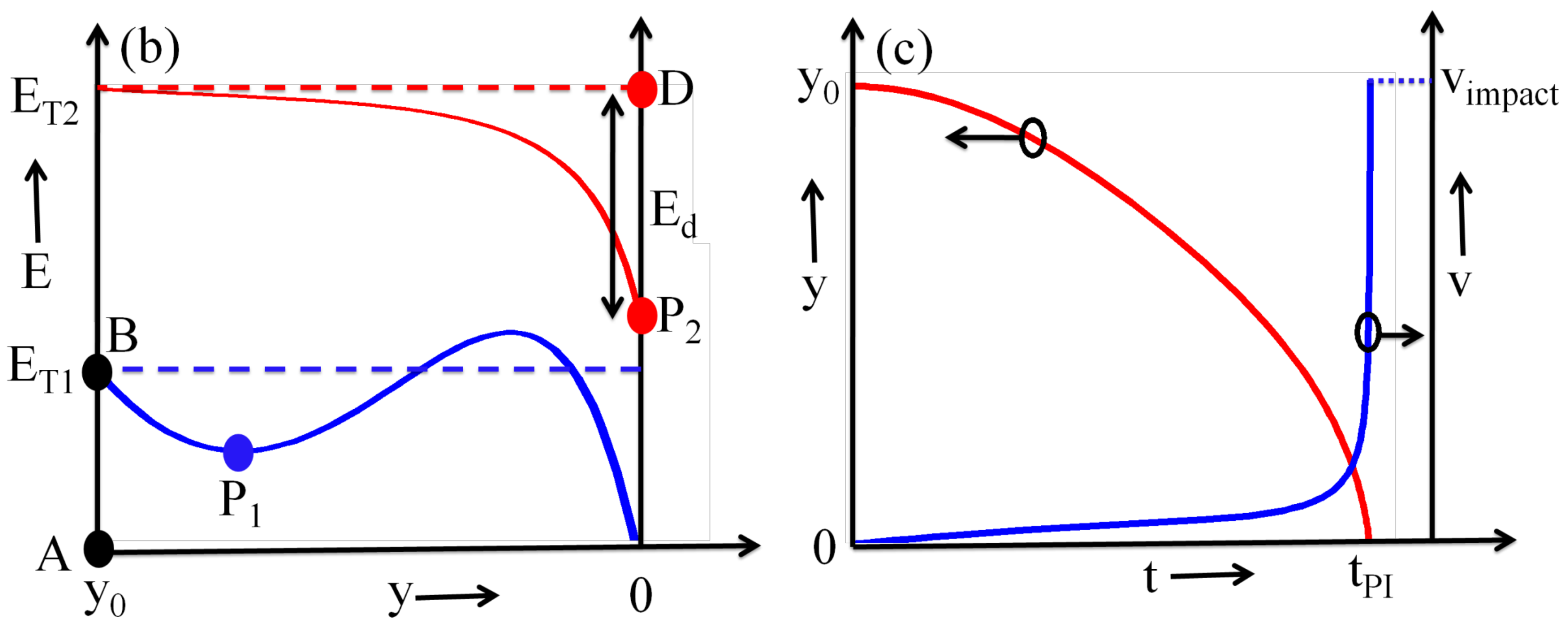


Fig. (b):Total energy (sum of electrostatic potential and spring potential energy) plotted as a function of gap (y). Below pull-in (blue curve), potential energy has a minimum (point P_1) and electrode M_1 stabilizes there. Above pull-in (red curve), potential energy does not have any minimum and therefore electrode M_1 is pulled down.

Fig.(c) Displacement (y) and velocity (v) as a function of time (t) during pull-in. Velocity increases rapidly just before hitting the dielectric. M_1 hits the dielectric with v_{impact} and that damages the surface of the dielectric due to this energy dissipation (E_d=1/2mv^2_{impact})

Soft Landing: Strategies

$$F_{elec} = \frac{1}{2}\left(C^2\frac{dV_c}{dy} + V_c\frac{dC^2}{dy}\right) \qquad C = \frac{\varepsilon_0\varepsilon_r A_{eff}(y)}{y_d + \varepsilon_r y}$$

➢Waveform shaping: modify input voltage V dynamically

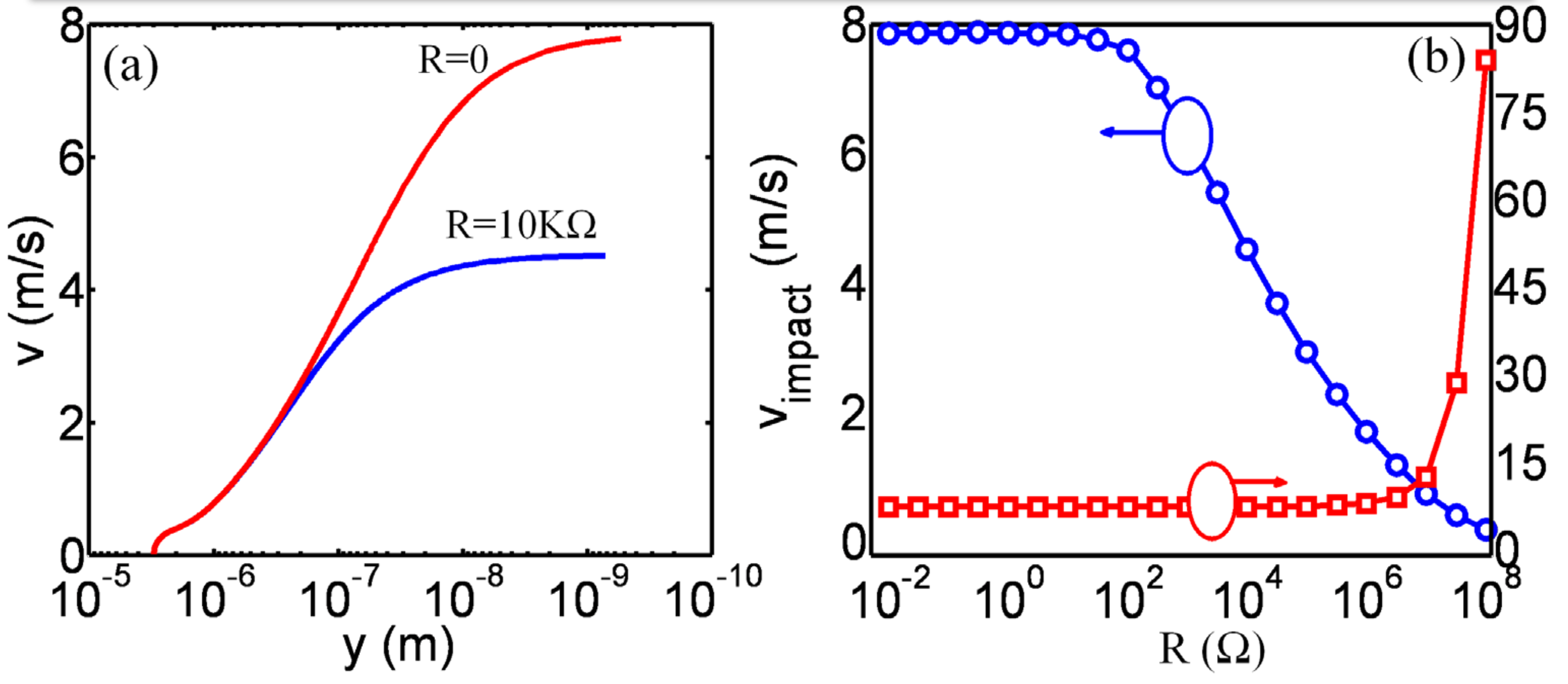
➢Resistive Braking: Modify V_c dynamically
- ❖Energy is dissipated in a remote resistance
- ❖Does not affect pull-in voltage and pull-in time

➢ Capacitive Braking: Modify $A_{eff}(y)$ Dynamically
- ❖Patterning of electrode M_1/M_2 or dielectric
- ❖Does not affect pull-in voltage as pull-in occurs at 2/3y_0 and all the field lines from the individual elements merge making it look like a flat plate electrically
- ❖Does not affect pull-in time

Resistive Braking

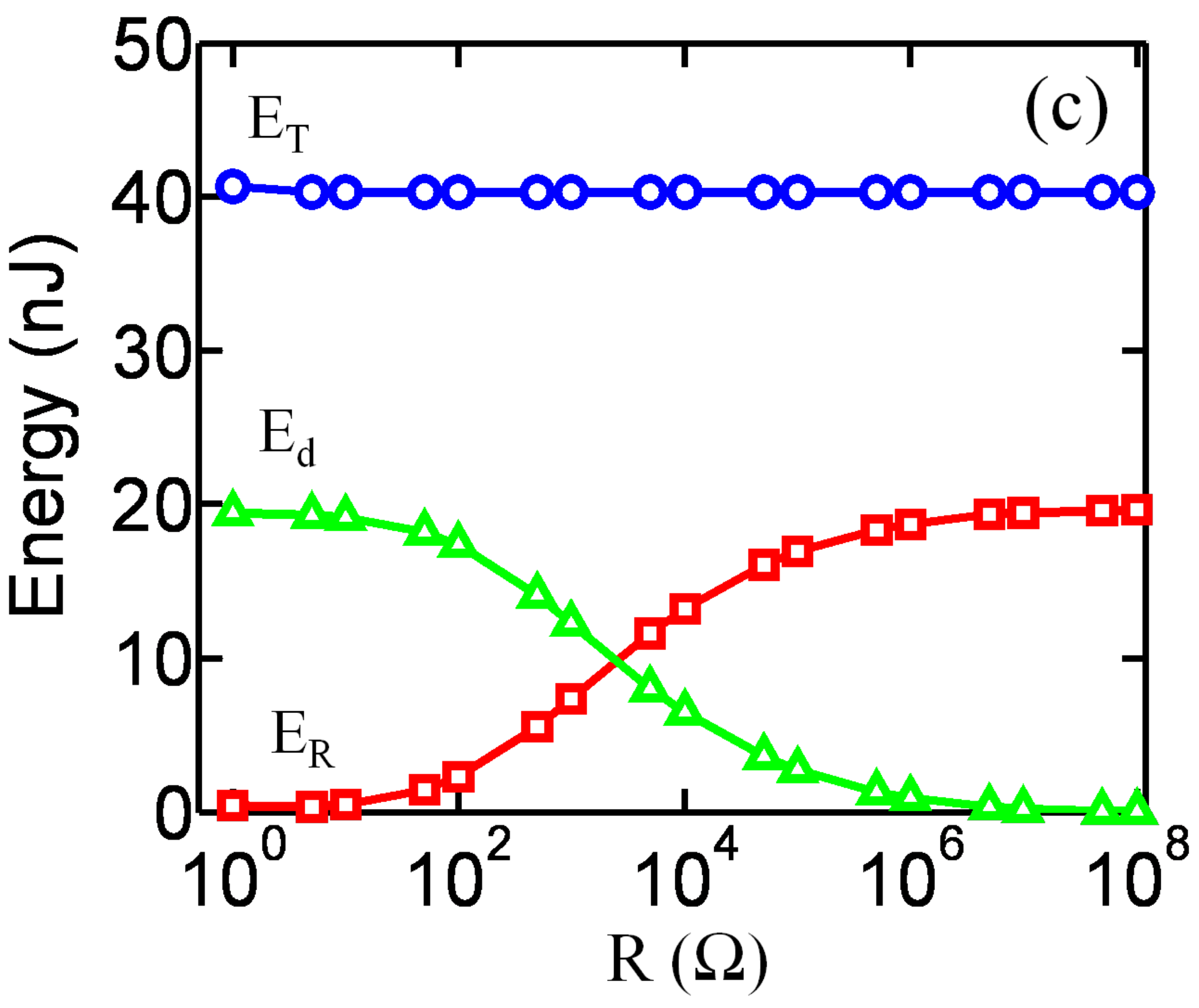
$$m\frac{dv}{dt} = k(y_0 - y) - \frac{0.5\varepsilon_r^{\ 2}AV_c^{\ 2}}{(y_d + \varepsilon_r y)^2} \qquad \frac{dy}{dt} = v$$

$$\frac{dV_c}{dt} = \frac{(V - V_c)(y_d + \varepsilon_r y)}{R\varepsilon_r\varepsilon_0 A} + \frac{V_c\varepsilon_r}{y_d + \varepsilon_r y}v$$



- ❖ Remote resistance causes dramatic reduction in the impact velocity
- ❖ Remote resistance below 1MΩ does not change the pull-in time significantly

Energy Dissipation during Resistive Braking



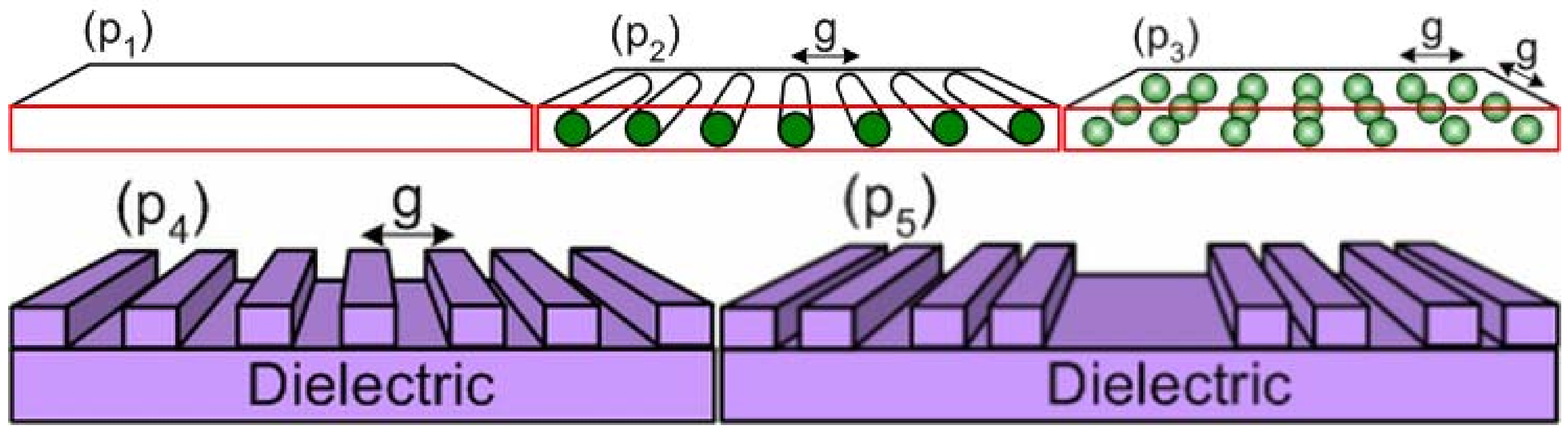
E_T: Total energy supplied by the voltage source.

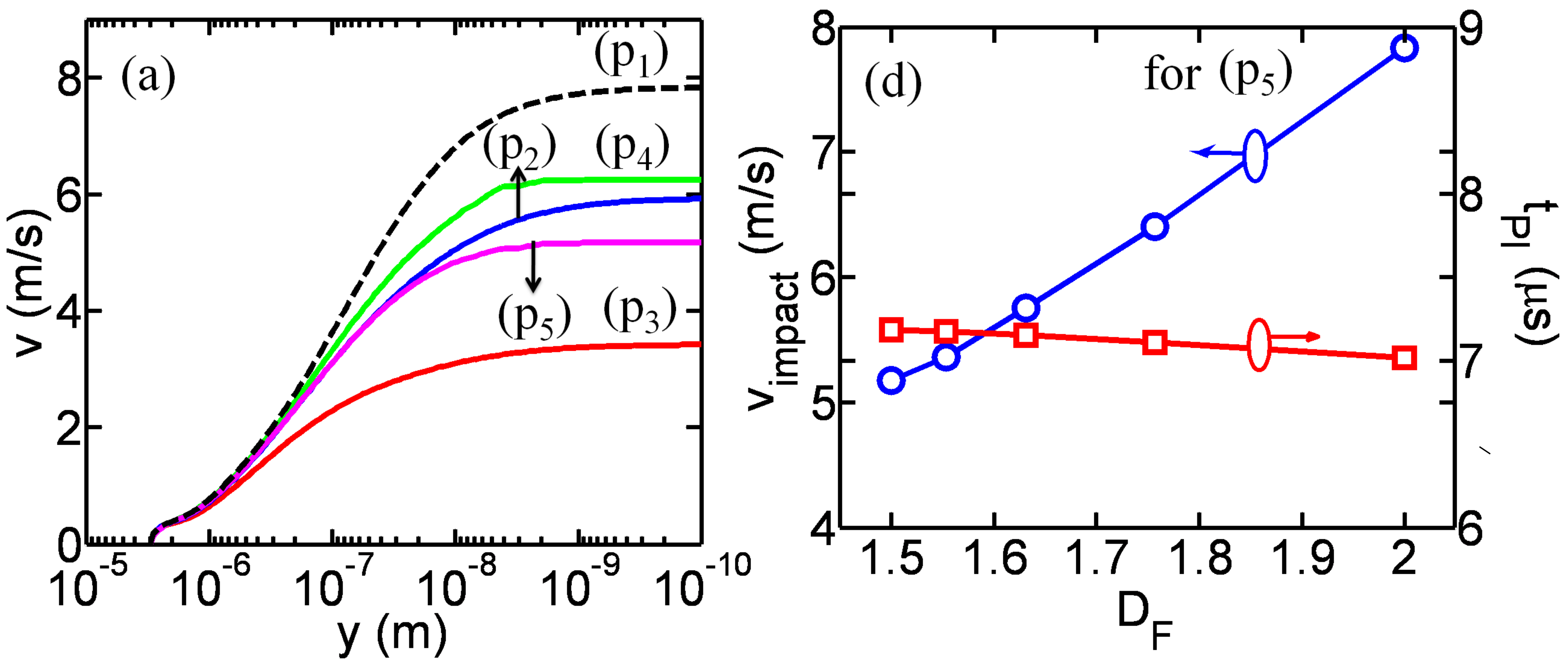
E_d (=1/2mv^2_{impact}): Total energy dissipated at the dielectric surface.

E_R(=$\int I^2Rdt$): Total energy dissipated in the remote resistance.

- ❖ Total energy supplied by the voltage source E_T is independent of the resistance
- ❖ Surface dissipation E_d decreases at the cost of increased remote resistive dissipation E_R

Capacitive Braking





- ❖ Patterning of electrode M1/M2 or dielectric reduces the impact velocity
- ❖ Patterning does not change the pull-in voltage and pull-in time significantly
- ❖ For p_5 impact velocity decreases with the decreases in fractal dimension D_F

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Conclusion

- ❖ Two novel techniques for reducing impact velocity are proposed which do not require any complex external circuitry.
- ❖ Resistive braking requires putting a resistance in series with the voltage source.
- ❖ Capacitive braking requires patterning of the electrode or the dielectric.