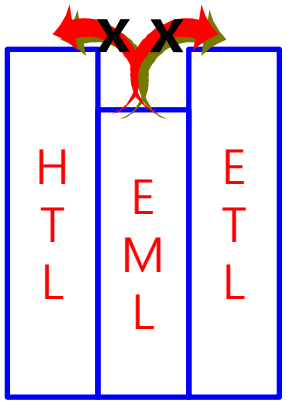
Host strategy for blue organic light-emitting diodes

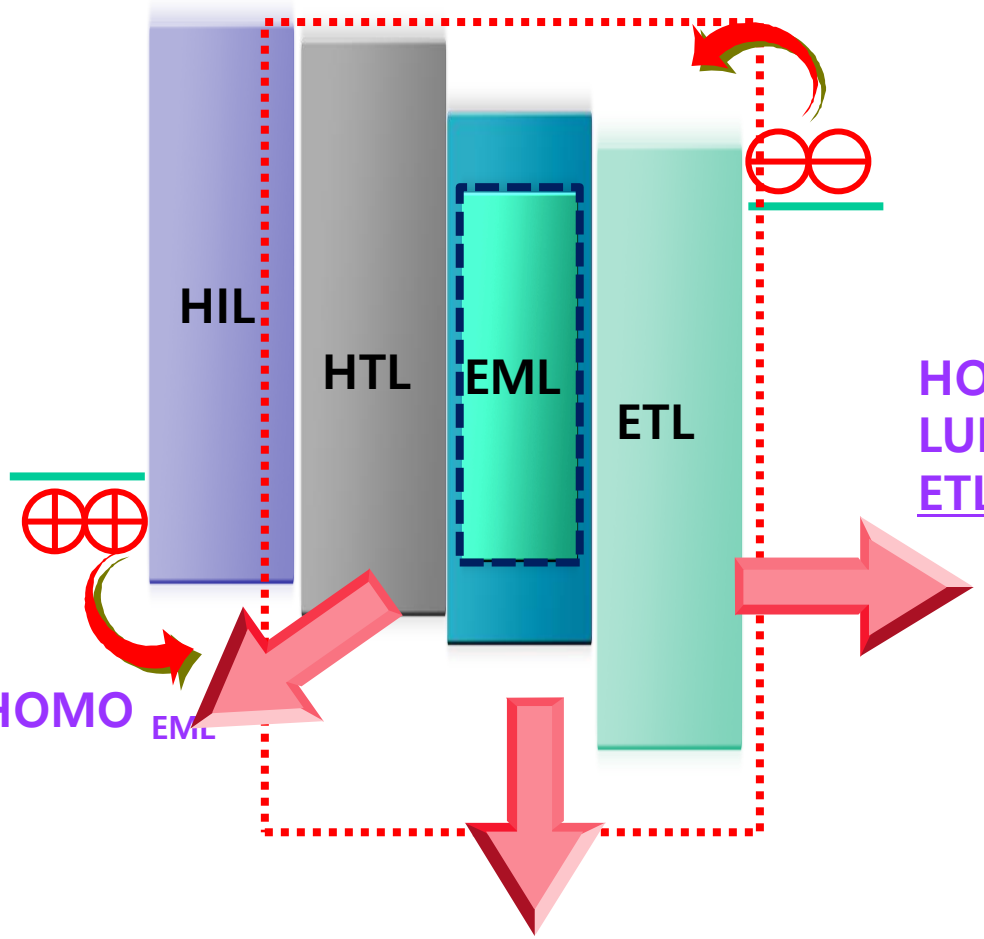
Prof. Jun Yeob Lee

Organic Electronics Lab. School of Chemical Engineering
Sungkyunkwan University, KOREA

Device design of blue PHOLED or TADF OLED

Triplet energy diagram



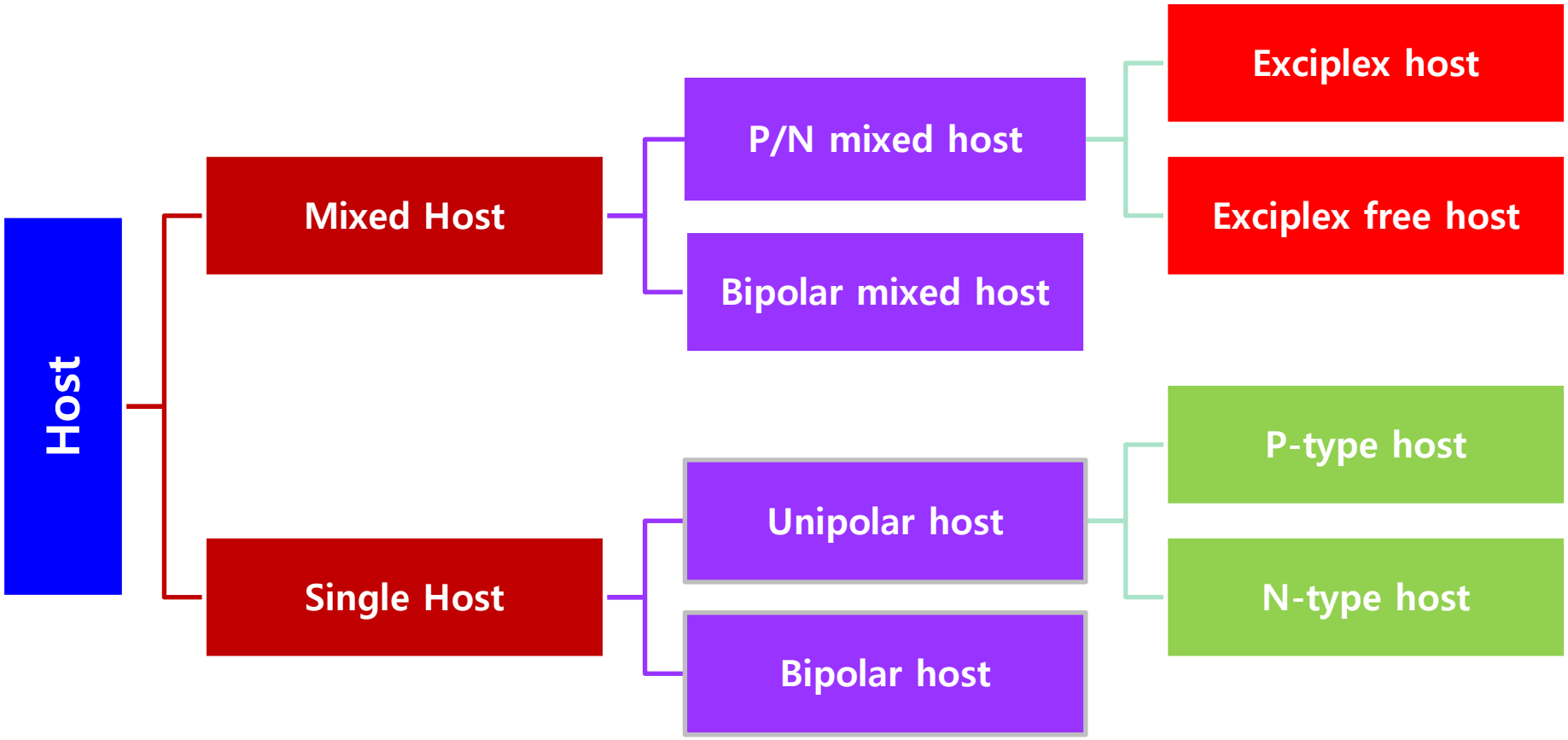


$HOMO_{ETL} > HOMO_{EML}$
$LUMO_{ETL} = LUMO_{EML}$
$ETL(E_T) > EML(E_T)$

$HOMO_{HIL} < HOMO_{HTL} = HOMO_{EML}$
$LUMO_{HTL} < LUMO_{EML}$
$HTL(E_T) > EML(E_T)$

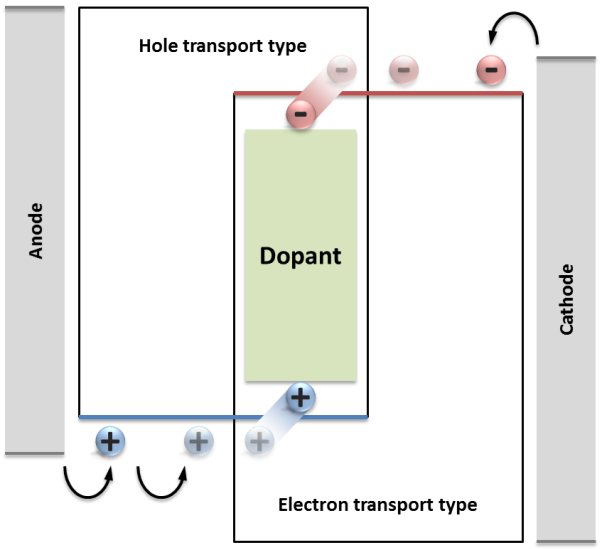
- High triplet energy host ($Host(E_T) > Dopant(E_T)$)
- Bipolar charge transport properties (carrier balance)
- Suppression of degradation mechanism (TTA, TPA)
- Stability under positive/negative polaron, singlet/triplet exciton

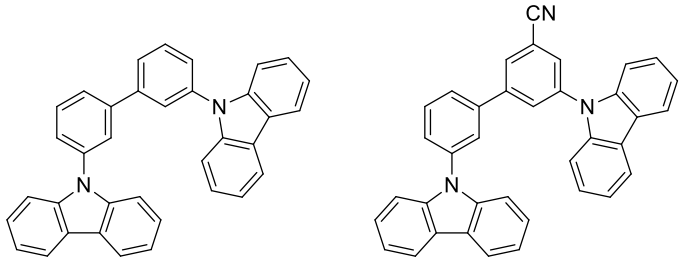
Host material classification



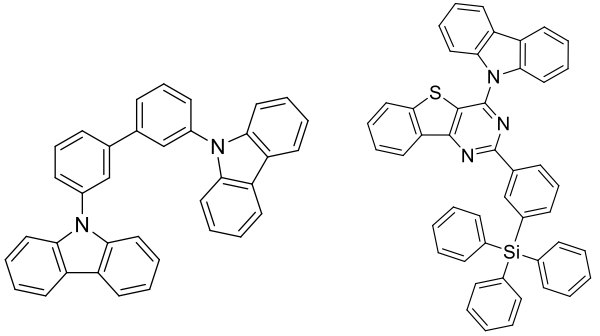
Mixed host (Exciplex free)

- ✓ Carrier balance : high EQE/small EQE roll-off
- ✓ Low driving voltage
- ✓ Wide emission zone
- ✓ Hole/electron stability
- ✓ TPA triggered degradation (charge trapping)
- ✓ Degradation by leaked carriers





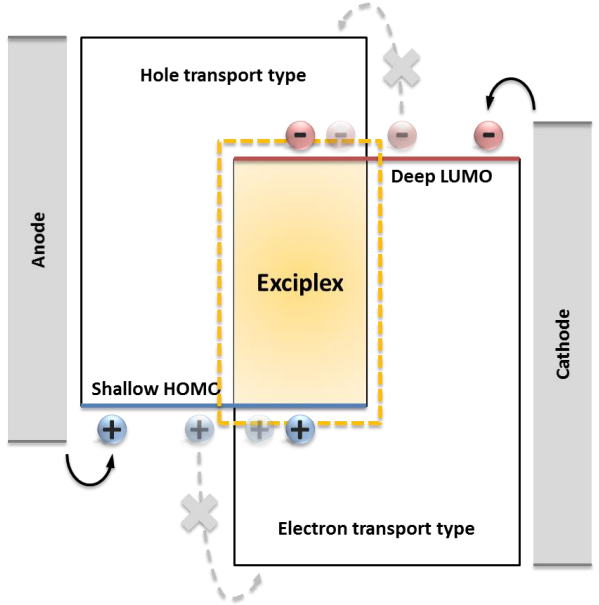
J. Y. Lee et al. J. Mater. Chem. 6, 10308 (2018)

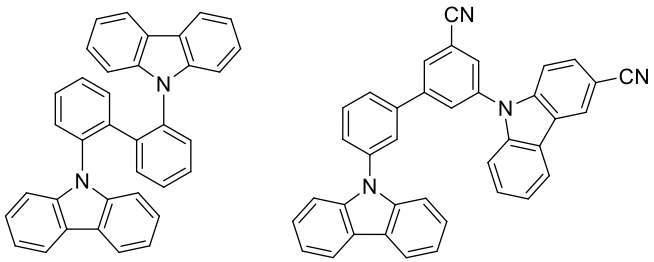


J. Y. Lee et al., ACS Appl. Mater. Inter. 12, 19737 (2020)

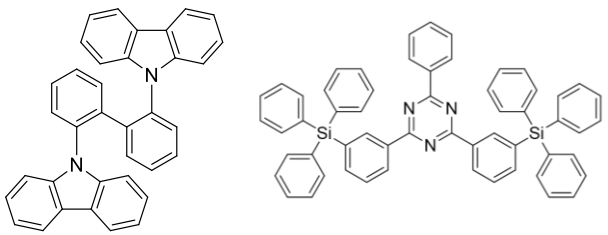
Mixed host (Exciplex)

- ✓ Carrier balance : high EQE/small EQE roll-off
- ✓ Low driving voltage
- ✓ Low triplet energy
- ✓ Wide emission zone
- ✓ Hole/electron stability
- ✓ Suppressed degradation (energy transfer)





J. Y. Lee et al. J. Mater. Chem. 6, 10308 (2018)

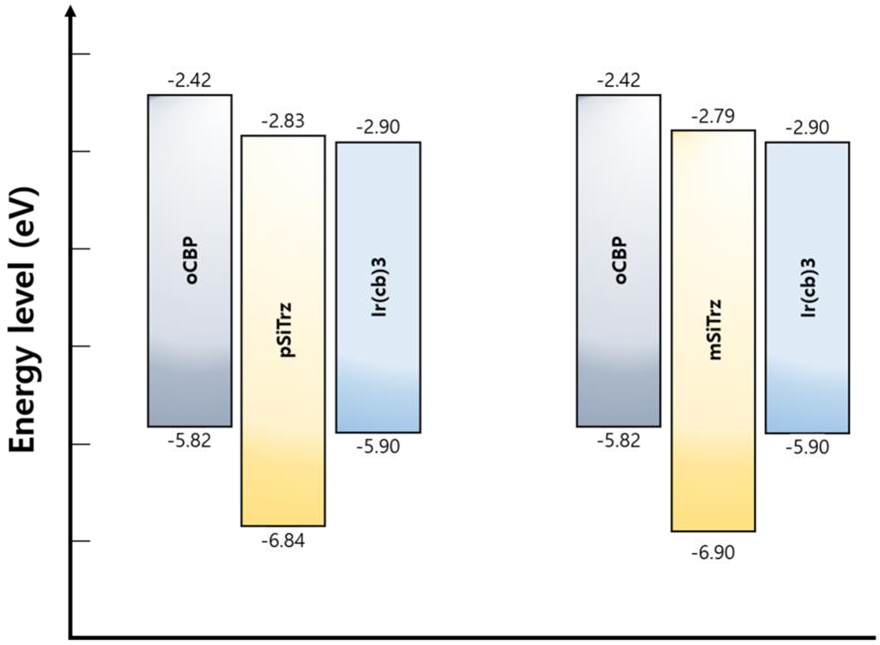


J. Y. Lee et al. Adv. Opt. Mater. 1901374 (2019)

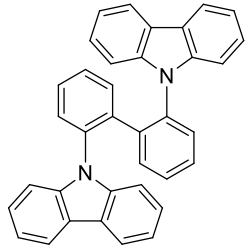
Exciplex host for deep blue phosphor

◆ **Exciplex host for deep blue device**

: high triplet energy n-host

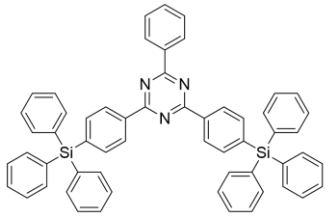


P-type Host

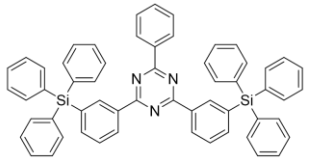


oCBP

N-type Host



pSiTrz



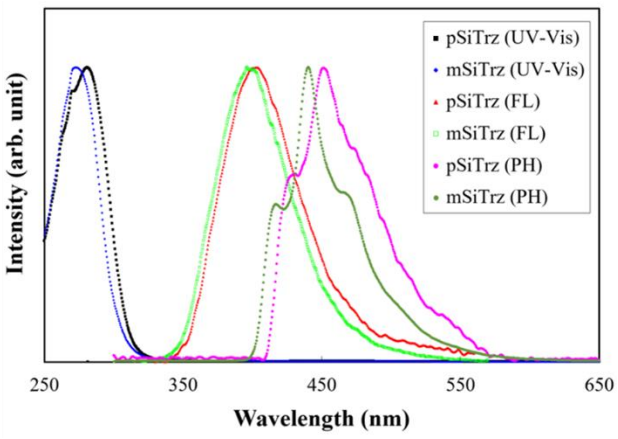
mSiTrz

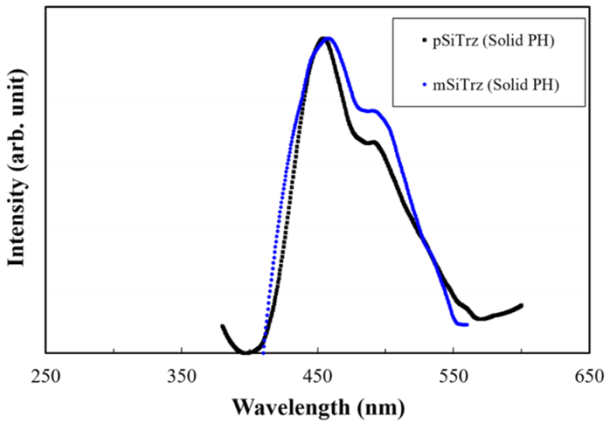
J. Y. Lee et al. Adv. Opt. Mater. 1901374 (2019)

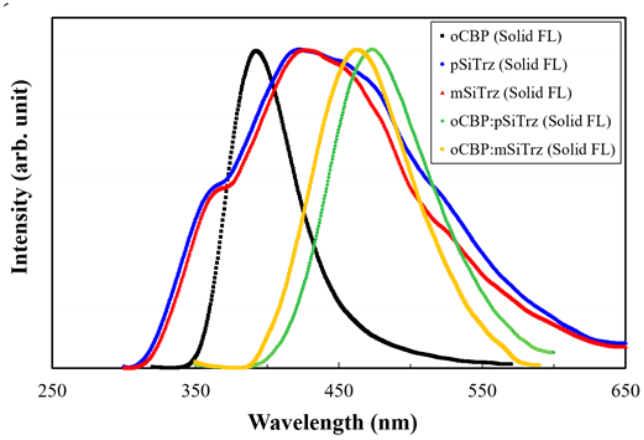
Exciplex host for deep blue phosphor

◆ Exciplex host for deep blue device

: high triplet energy p- and n-host





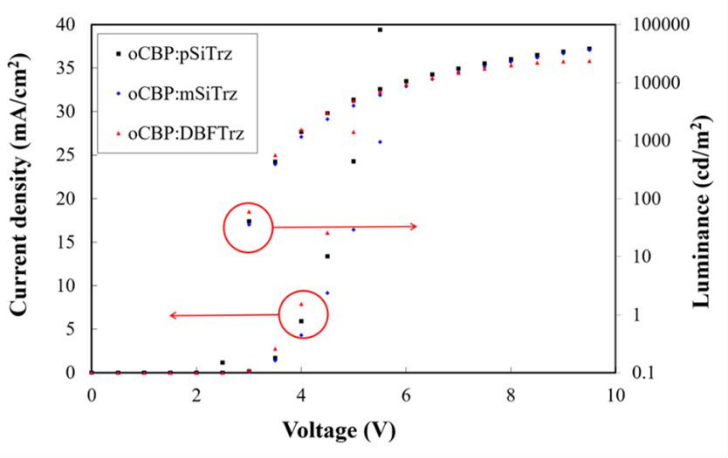


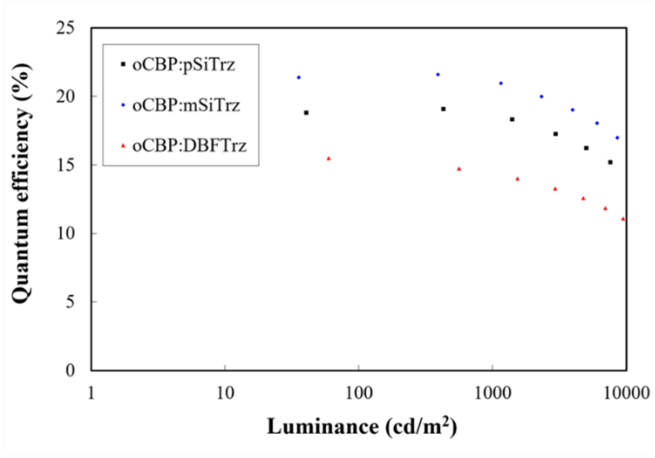
	UV-vis edge (nm)	Singlet energy (eV)	Triplet Energy (solution) (eV)	Triplet Energy (solid) (eV)	HOMO (eV)	LUMO (eV)	T_g (°C)	T_d (°C)
pSiTrz	309	3.54	3.01	**2.99**	-6.84	-2.83	129.9	489.2
mSiTrz	302	3.56	3.08	**3.02**	-6.90	-2.79	108.2	464.9

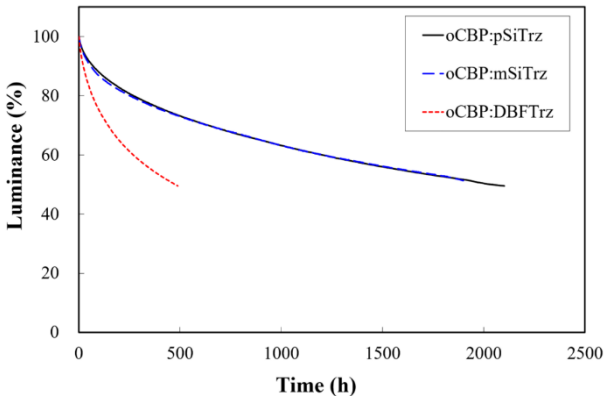
Exciplex host for blue phosphor

◆ Exciplex host for blue device

: high triplet energy p and n type host





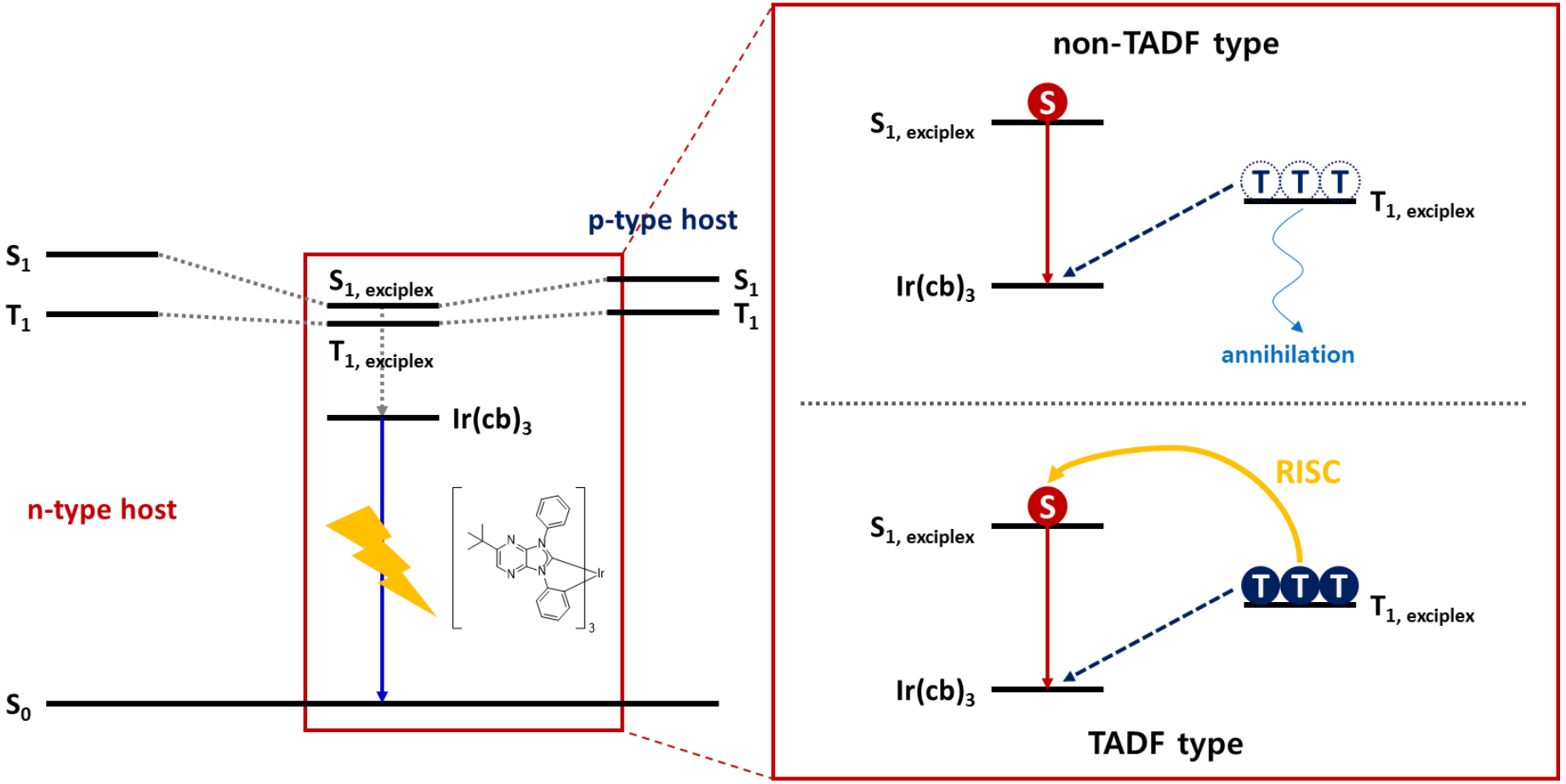


Device	100 cd/m²		EQE (%)			P.E (lm/W)		
	CIE	LT_{50} (h)	100 cd/ m²	1000 cd/ m²	Max	100 cd/m²	1000 cd/m²	Max
oCBP:pSiTrz:Ir(cb)3	0.14, 0.16	1,900	18.9	18.6	19.1	25.5	20.2	26.1
oCBP:mSiTrzIr(cb)3	0.14, 0.16	1,900	21.4	21.1	21.6	28.6	21.9	29.3
oCBP:DBFTrz:Ir(cb)3	0.14, 0.18	500	15.4	14.4	15.5	22.5	17.0	22.8

TADF type exciplex host for blue phosphor

◆ TADF type exciplex host for blue device

: triplet exciton conversion into singlet exciton

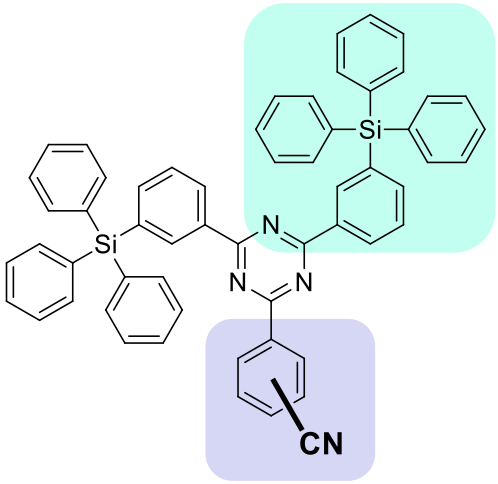


J. Y. Lee et al. Chem. Eng. J. 2020 Accepted

TADF type exciplex host for blue phosphor

◆ Exciplex host for blue device

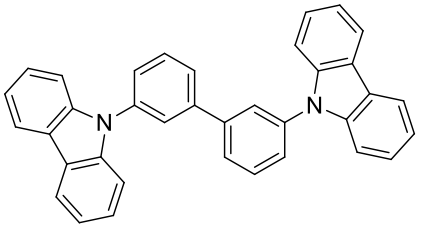
: high triplet energy n type host



Triphenylsilyl
- blocking group
- high E_T in solid state
- small binding energy

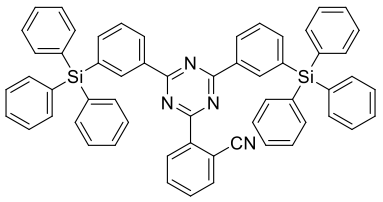
Benzonitrile
- electron transport property
- control of the LUMO level

P-type Host

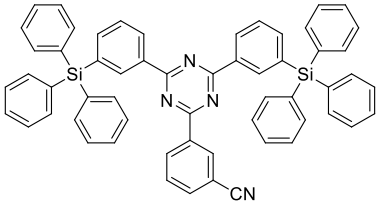


mCBP

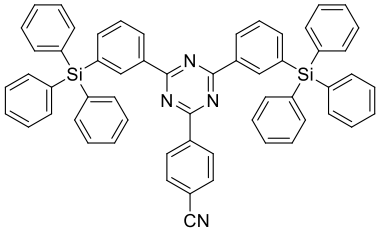
N-type Host



mSiTrz-oCN



mSiTrz-mCN



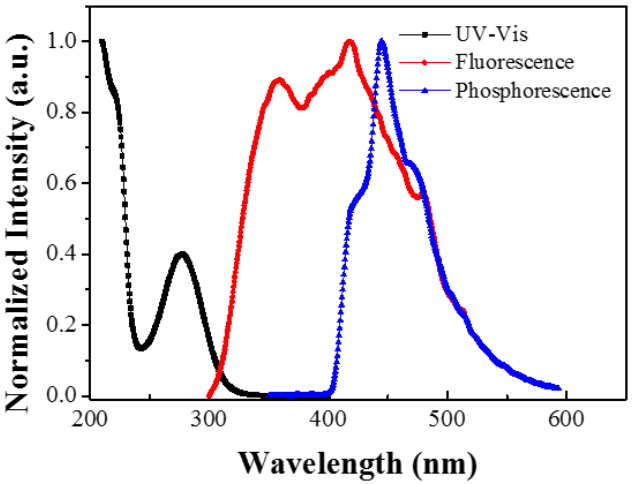
mSiTrz-pCN

TADF type exciplex host for blue phosphor

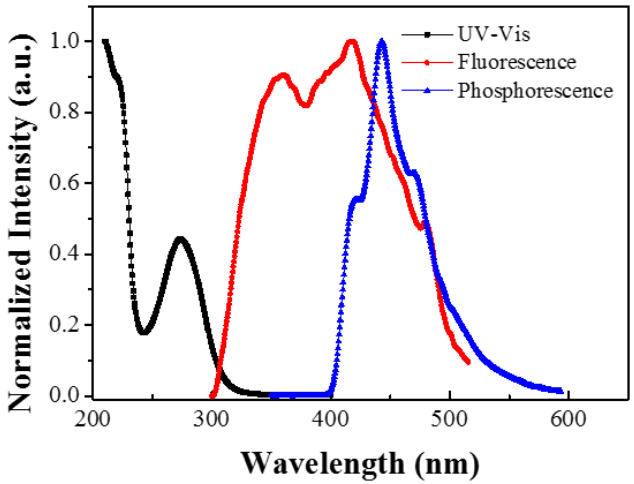
◆ n-type host for exciplex

: high triplet energy

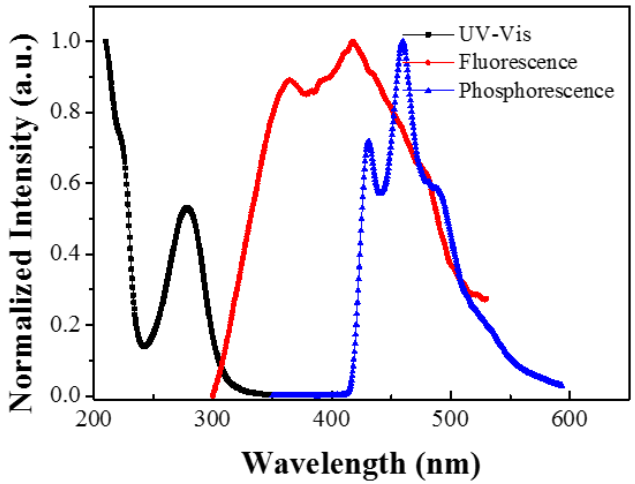
<mSiTrz-oCN>



<mSiTrz-mCN>



<mSiTrz-pCN>



	λ_{onset} (nm)[a]	E_g (eV)	λ_{FL} (nm) [b]	E_S (eV)	λ_{PH} (nm) [c]	E_T (eV)
mSiTrz-oCN	312	3.97	359	3.45	419	**2.96**
mSiTrz-mCN	308	4.03	359	3.45	417	**2.97**
mSiTrz-pCN	307	4.04	366	3.39	431	**2.88**

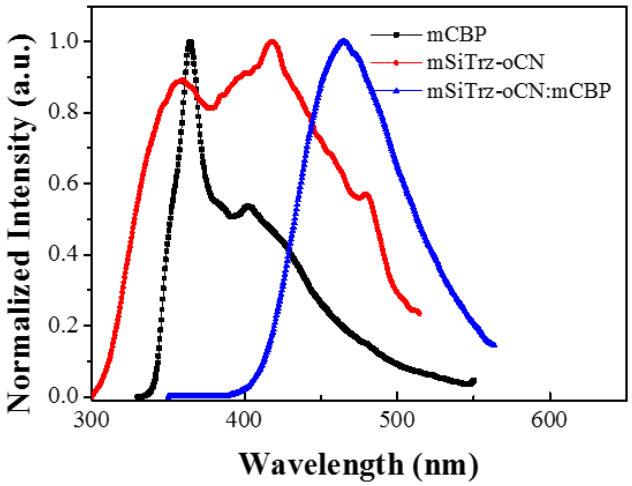
[a] λ_{onset} is onset value of UV-Vis spectrum
[b] λ_{FL} is first peak of fluorescence emission spectrum
[c] λ_{PH} is first peak of phosphorescence emission spectrum

TADF type exciplex host for blue phosphor

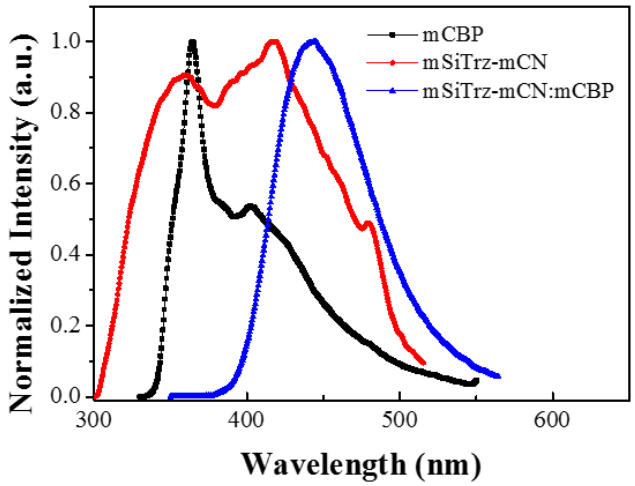
◆ mCBP/n-type host for exciplex

: high triplet energy exciplex formation

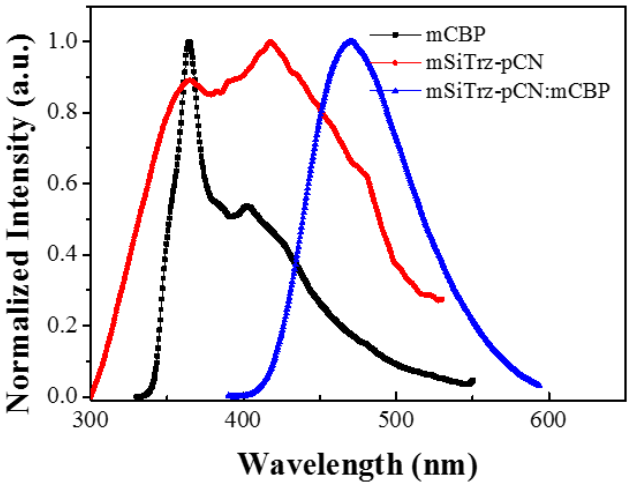
<mSiTrz-oCN:mCBP>



<mSiTrz-mCN:mCBP>



<mSiTrz-pCN:mCBP>



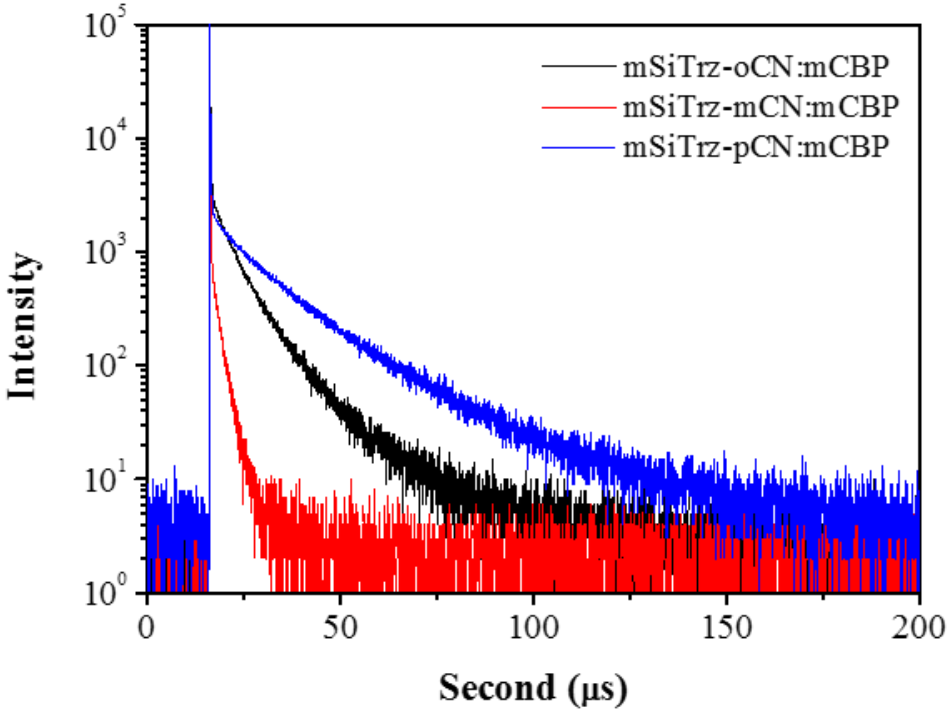
	$\lambda_{max,\ FL}$ (nm) [a]	E_S (eV) [b]	$\lambda_{max,\ PH}$ (nm) [c]	E_T (eV) [d]	ΔE_{ST}
mSiTrz-oCN:mCBP	465	**3.02**	454	2.93	0.09
mSiTrz-mCN:mCBP	445	**3.12**	443	2.98	0.14
mSiTrz-pCN:mCBP	471	**2.96**	468	2.88	0.08

[a] $\lambda_{max,FL}$ is max peak of fluorescence emission spectrum of mixed film
[b] E_S is calculated from onset value of fluorescence emission spectrum of mixed film
[c] $\lambda_{max,\ PH}$ is max peak of phosphorescence emission spectrum of mixed film
[d] E_T is calculated from onset value of phosphorescence emission spectrum of mixed film

TADF type exciplex host for blue phosphor

◆ **mCBP/n-type host for exciplex**

: high triplet energy exciplex formation



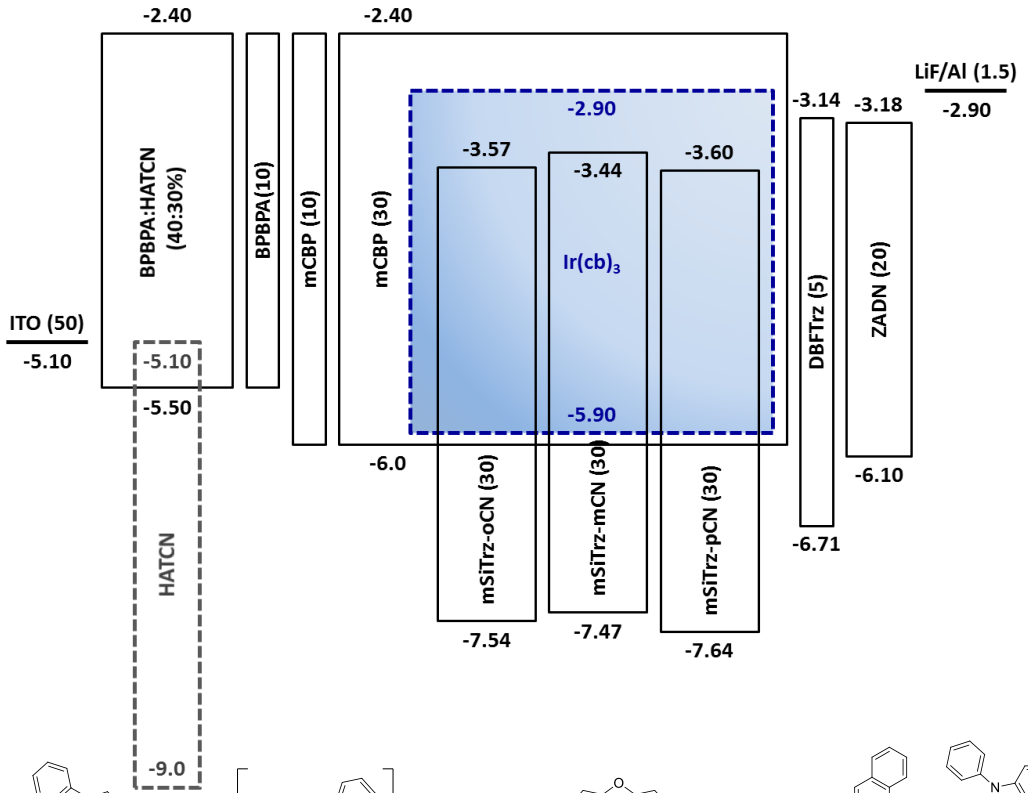
	τ_d (μs) [a]
mSiTrz-oCN:mCBP	8.1
mSiTrz-mCN:mCBP	4.6
mSiTrz-pCN:mCBP	17.7

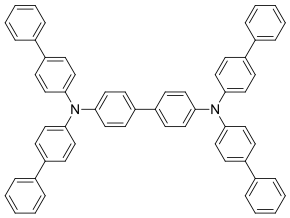
[a] τ_d is excited state lifetime of delayed component

TADF type exciplex host for blue phosphor

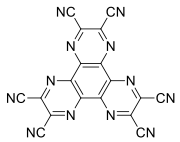
◆ Device structure

LiF/Al (1.5 nm + 200 nm)
ZADN (20 nm)
DBFTrz (5 nm)
mCBP:X:Ir(cb)$_3$ (30 nm : 20wt%)
mCBP (10 nm)
BPBPA (10 nm)
BPBPA:HATCN (40 nm : 30wt%)
ITO

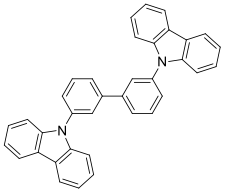




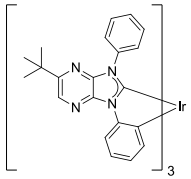
BPBPA



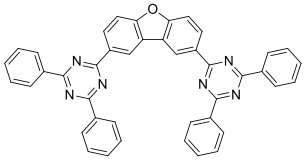
HATCN



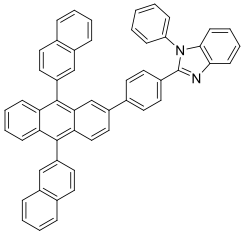
mCBP



Ir(cb)$_3$



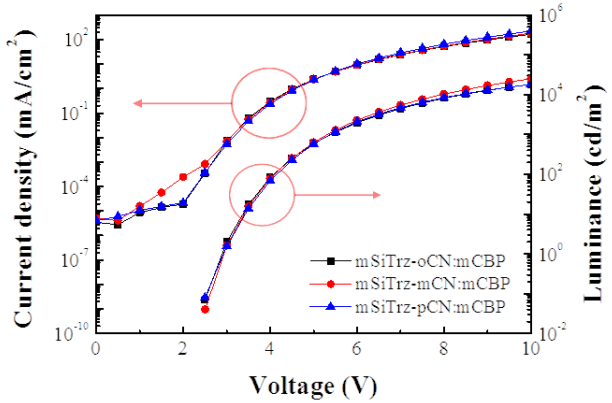
DBFTrz

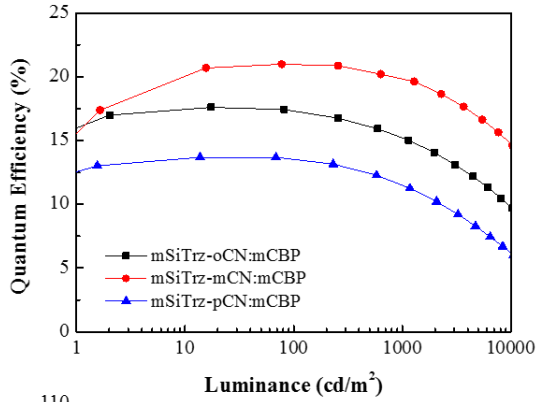


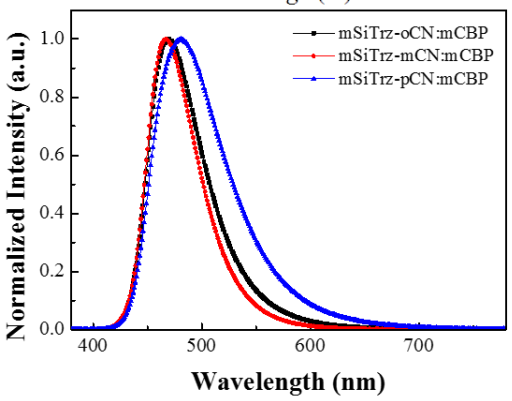
ZADN

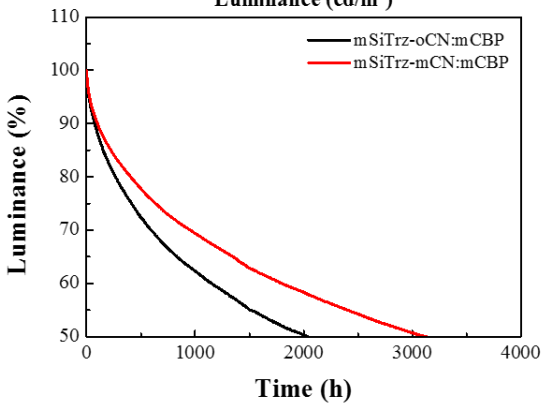
TADF type exciplex host for blue phosphor

◆ Device performances





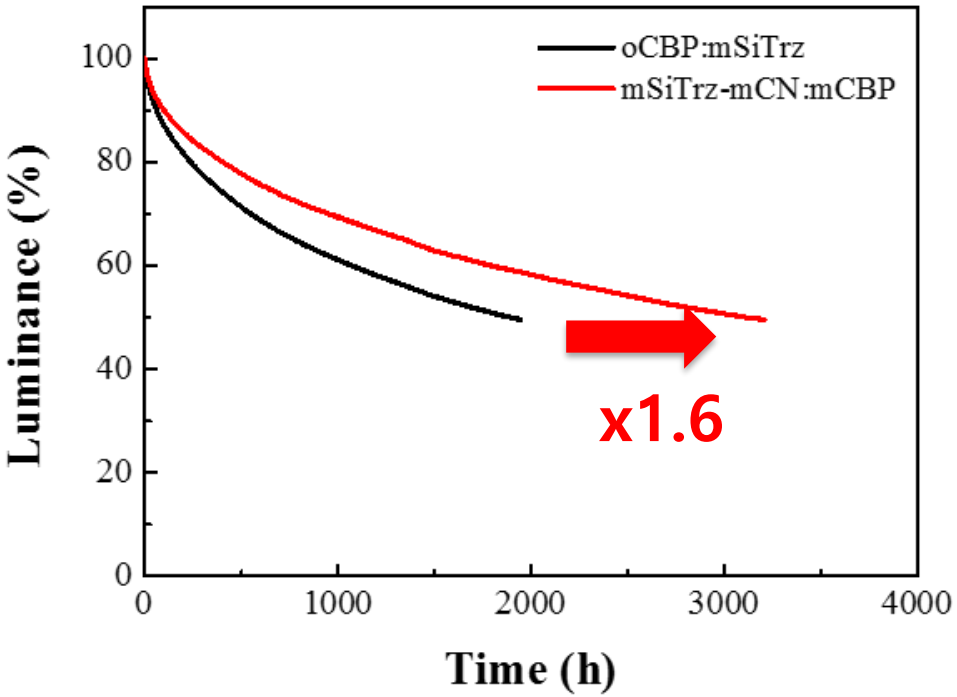


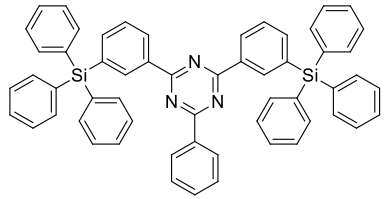


	V_{on} (V)	EQE (%)			PE (lm/W)			CIE	Lifetime (h, LT_{50})	
		100 cd/m²	1000 cd/m²	Max	100 cd/m²	1000 cd/m²	Max		100 cd/m²	1000 cd/m²
mSiTrz-oCN:mCBP	2.74	17.4	15.3	17.6	21.6	14.1	29.5	(0.15, 0.22)	2040	32
mSiTrz-mCN:mCBP	2.80	21.0	19.9	21.0	22.1	16.0	25.5	(0.14, 0.18)	3130	50
mSiTrz-pCN:mCBP	2.81	13.6	11.6	13.7	22.2	14.1	30.0	(0.18, 0.32)	-	-

TADF type exciplex host for blue phosphor

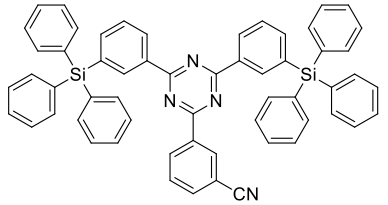
◆ Device performances





mSiTrz

*K. H. Choi et al., Adv. Opt. Mater., 2019, **7**, 1901374*

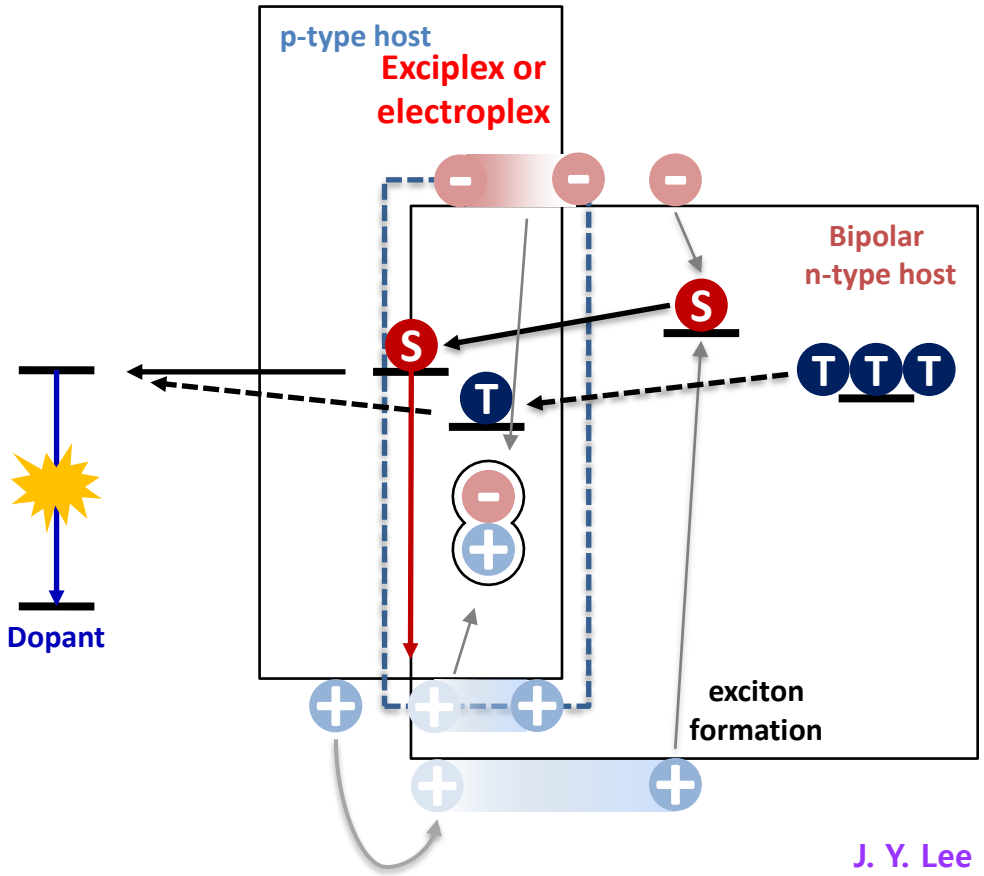


mSiTrz-mCN

Bipolar n-host for electroplex type host

◆ Design concept

- bipolar n-type host to stabilize leaked holes
- bipolar n-type host to stabilize excitons
- exciplex or electroplex formation for energy transfer

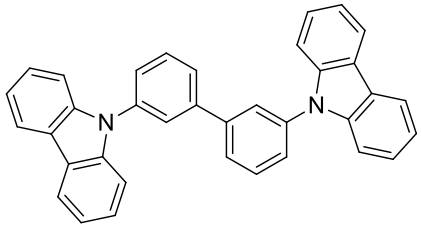


J. Y. Lee et al. Mater. Horizon. 2020

Bipolar n-host for electroplex type host

◆ Design concept

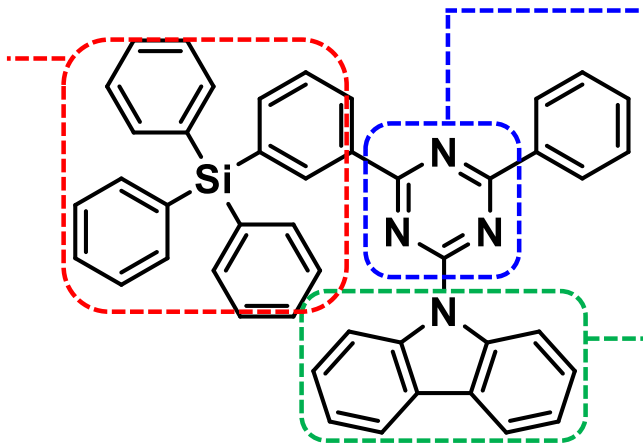
- bipolar n-type host to stabilize leaked holes
- bipolar n-type host to stabilize excitons
- exciplex or electroplex formation for energy transfer



mCBP

Blocking Group

Limited molecular packing in solid state
High triplet energy
Electron transport



Triazine

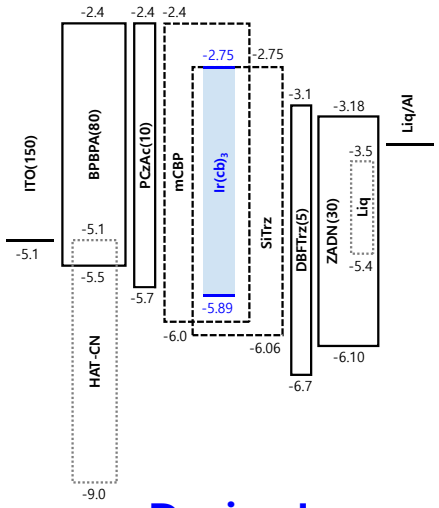
Electron transport
High triplet energy

Carbazole

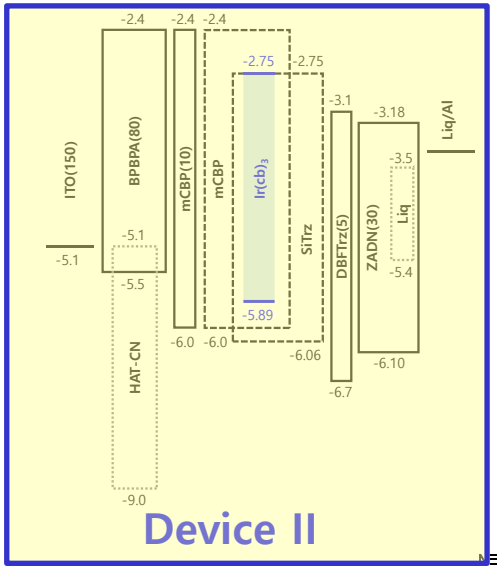
Low emission energy
Hole stability

Bipolar n-host for electroplex host

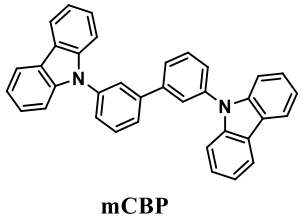
◆ Deep blue PHOLEDs

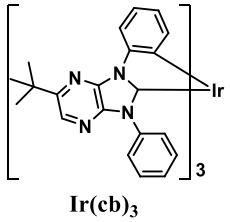


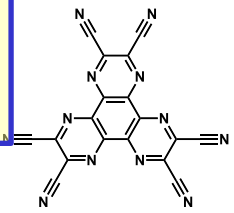
Device I

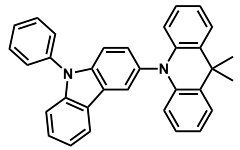


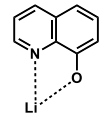
Device II

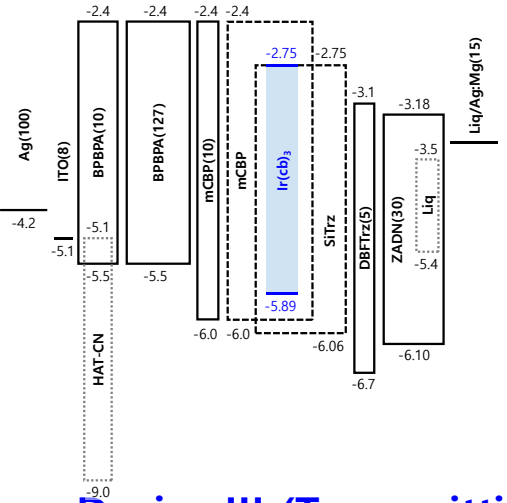




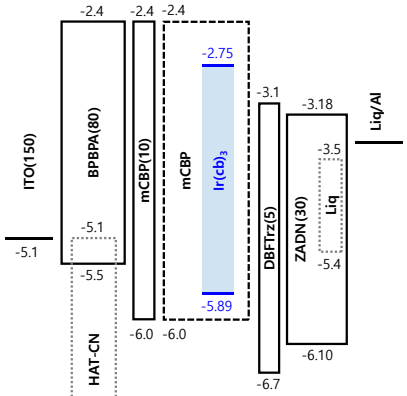




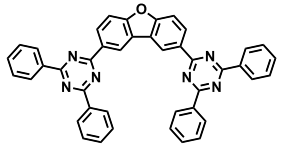


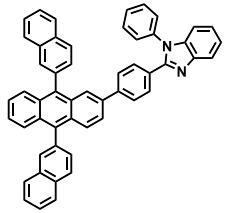


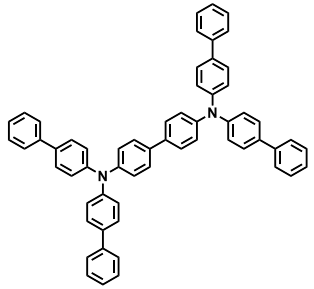
Device III (Top-emitting)



Reference

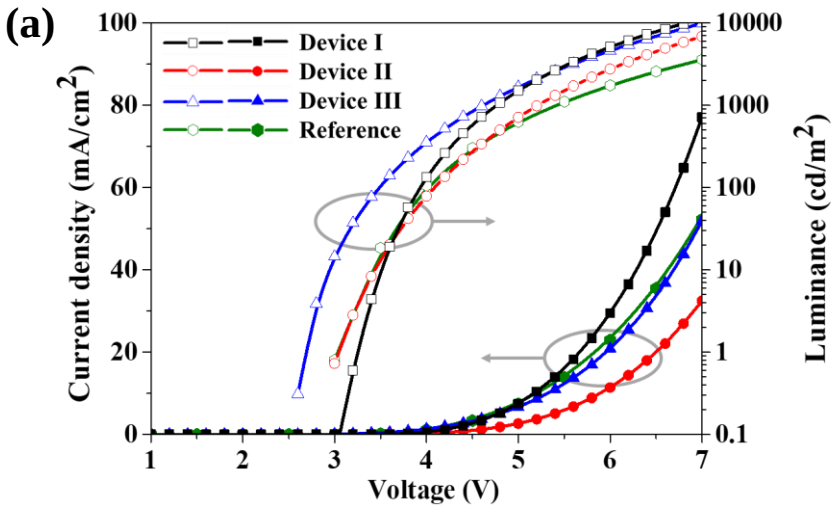


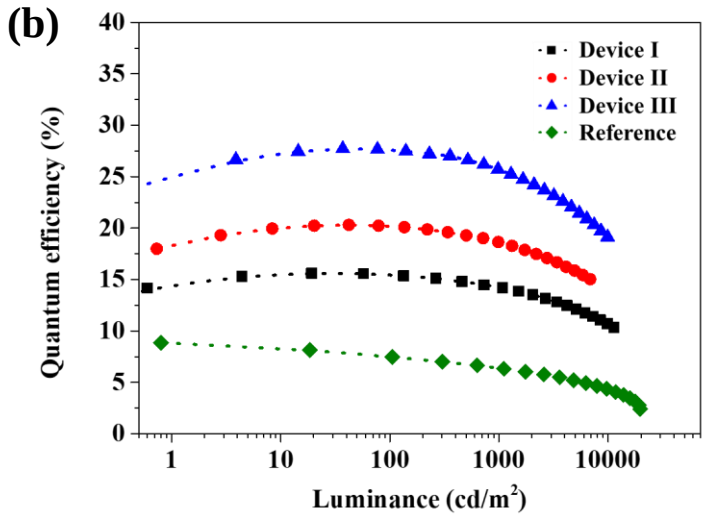


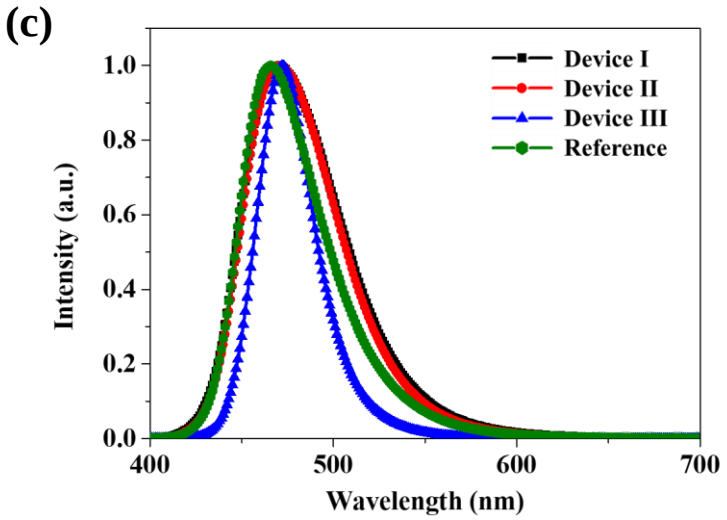


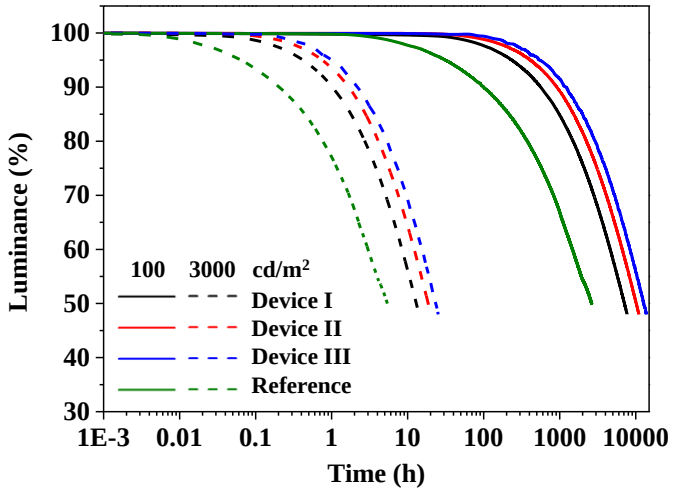
Bipolar n-host for electroplex host

◆ Deep blue PHOLEDs



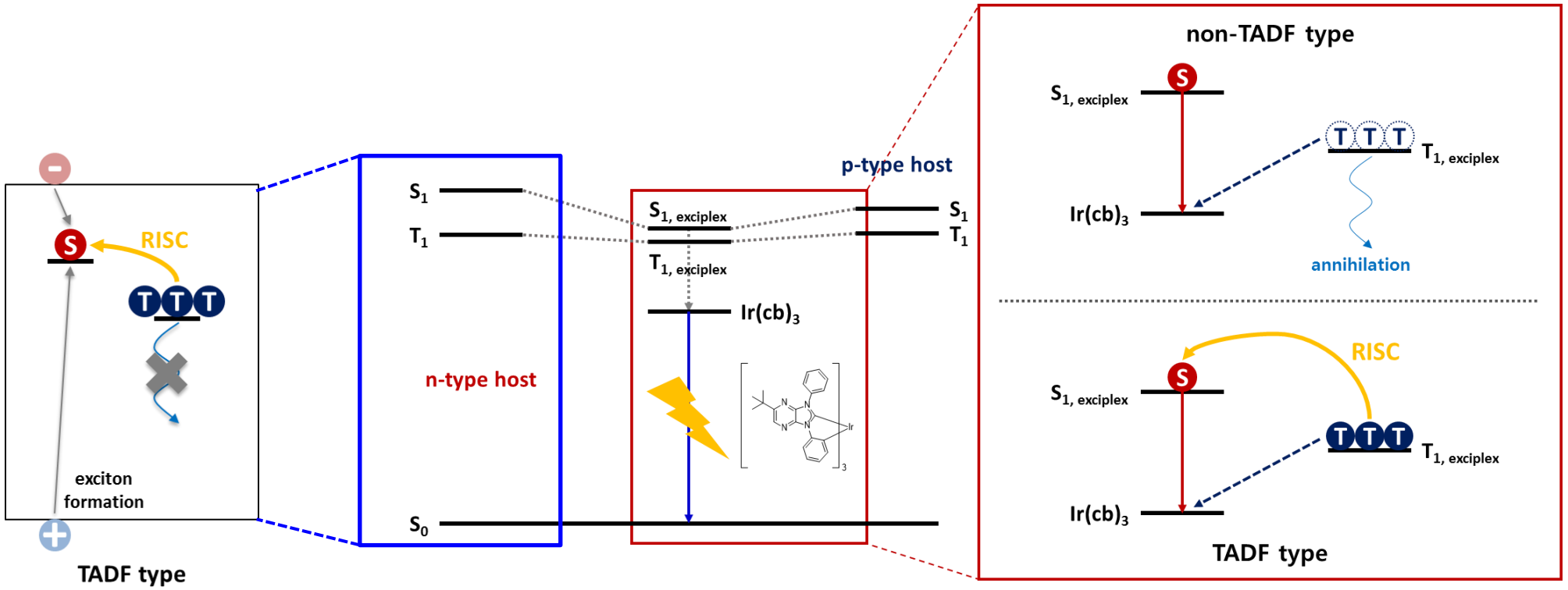






Advanced approach

◆ TADF type exciplex using TADF type host



Acknowledgements

Synthesis

V. Patil (Postdoc)
S Kotavale (Postdoc)
H. L. Lee (MS/Ph.D)
S. H. Jeong (Ph.D)
J. H. Park (Ph.D)
J. H. Kang (MS/Ph.D)
E. G. Lee (MS)
S. J. Yoon (MS)
Y. S. Kim (MS)
J. A. Kang (MS)
J. S. Ha (MS)
D. J. Shin (MS)

Device

J. M. Kim (Postdoc)
H. J. Jang (MS/Ph.D)
K. H. Lee (MS/Ph.D)
W. J. Jeong (MS)
J. S. Lim (MS)