SuperKEKB Status and SOI Pixel R&D

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Part I
SuperKEKB Status
SuperKEKB overview

Peak luminosity: $8 \times 10^{35}$/cm$^2$/s ($\sim 50 \times$ present world record from KEKB)

Integrated luminosity: 50/ab ($\sim 100 \times$ present world record from KEKB)

will reach $8 \times 10^{35}$ cm$^{-2}$s$^{-1}$.
Three factors to determine luminosity:

Stored current:
1.36/1.75 A (KEKB)
→ 4.1/9.4 A (SuperKEKB)

Beam–beam parameter:
0.059 (KEKB)
→ >0.24 (SuperKEKB)

Luminosity:
0.16 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1} (KEKB)
8 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1} (SuperKEKB)

Vertical $\beta$ at the IP:
6.5/5.9 mm (KEKB)
→ 3.0/3.0 mm (SuperKEKB)
Peak Luminosity History and Prospects

Major upgrade or KEKB (SuperKEKB)
SuperKEKB chronicle

• 2001: Activity started
• 2004
  – SuperKEKB LoI (276 authors)
  – Physics part posted on hep-ex (hep-ex/0406071)
• 2005
  – First budget request from KEK (“gaisan” request) to MEXT
• 2006
  – Target luminosity doubled: $4 \times 10^{35} \rightarrow 8 \times 10^{35}$
  – JAHEP “Prospects for Elementary Particle Physics”
    • KEKB major upgrade as part of JAHEP master plan
• 2007
  – Crab cavities installed, under detailed evaluation
  – Update of SuperKEKB physics part in preparation
  – Starting detector optimization studies
SuperKEKB chronicle

2007
- Crab cavities installed, under detailed evaluation
  - Update of SuperKEKB physics part in preparation
  - Starting detector optimization studies
KEKB colliding bunches

Finite crossing angle

Smallest beam size in the world in ring colliders

50 billion electrons

70 billion positrons

2.3 µm

7 mm

1.3 degree

Each bunch collides 100 thousand times/second

1284 bunches in each ring
Beam-beam parameter

Simulation by K. Ohmi

Head-on (crab)
(Strong-strong simulation)

crossing angle 30 mrad
(at the optimum tune)
Crab crossing scheme

RF deflector (crab cavity)

Kick

Electrons

Positrons

crossing angle

Head-on collision
Crab Cavity in He Vessel (3D)

- Support Rod
- Jacket Type Main He vessel
  - SUS316L
- Jacket Type Sub He vessel
- Coaxial Coupler (Nb)
- Stub Support
- Crab Cavity Cell
- Notch Filter
- Support Pipe
- Tuning Rod
- Input Coupler
- RF Absorber
- Extract $T_{M010}$, $T_{E111}$ Mode
  - Frequency Tuning
Installation into KEKB
Crab Cavity for LER
Crab Cavities in the Nikko Section
(1 cavity per ring)

LER

HER
Crab Crossing

bunch head
bunch tail

crab cavity
1 cavity per ring
beam

Orbits of bunch head and tail

2 cavities per ring
beam

IP
Specific Luminosity

Crab Crossing

Specific Luminosity

$I_{\text{bunch HER}} \times I_{\text{bunch LER}}$ [mA$^2$]
- H offset must be less than 40 \( \mu\text{m} \).
- H offset is now adjusted by a feedback to keep the horizontal beam-beam parameter.
- More intelligent feedback under consideration.

**Luminosity**

![Graph showing luminosity vs. horizontal offset. The graph includes lines for different current and offset conditions, such as 1.4 mA, 18 nm x 0.8 mA, 24 nm, 0.5 mrad, 1 mrad, and 2 mrad.](image)
Summary of crab cavity commissioning status and near-future plans

• We have already achieved the vertical beam-beam tune shift parameter of 0.08 in HER, which is higher than our record 0.064 with a correction of the geometric gain.

• Continue machine tuning at low currents [75mA(LER)/50mA(HER), 51 bunches] till advantage of crab crossing is more clearly observed (~1 month)

• Higher currents for physics runs.
SuperKEKB chronicle

- **2007**
  - Crab cavities installed, under detailed evaluation
  - Update of SuperKEKB physics part in preparation
  - Starting detector optimization studies
Grand questions in flavor physics

• Why three generations?
• Why masses and mixing parameters with strange patterns?
• Why did antimatter disappear in the early universe?
• ...

• The Standard Model (SM) does not give answers
  – Profound principles (of Gauge, Relativity, Quantum)
  – However, “Flavor Principle” is missing
• These exciting questions will remain unanswered even if SUSY is found at LHC.

Long-term step-by-step approach for precision measurements in flavor physics is necessary to answer these grand questions.
Quark Flavor Physics

- $V_{ud}$
- $V_{us}$
- $V_{cd}$
- $V_{cs}$
- $V_{tb}$
- $V_{td}$
- $V_{ts}$

Beyond CKM:

- $V_{ub}$
- $V_{cb}$

dark flavor?

Cabibbo-Kobayashi-Maskawa matrix
Super precise measurements at SuperKEKB

- If “dark flavor” discovered
  - Direct detection of new physics in the flavor sector
  - Measurements of TeV new physics parameters (if TeV new particles found at LHC)

- If “dark flavor” not discovered
  - New Physics below 1 TeV severely constrained even assuming Minimal Flavor Violation (MFV)
  - Strongly suggest some “flavor principle” that suppresses FCNC. Some scenarios can even be ruled out.
Examples of physics studies at SuperKEKB

1. Are there new CP-violating phases?
2. Are there new right-handed currents?
3. Are there effects from new Higgs fields?
4. Are there new flavor violation?
5. Is there new flavor symmetry to explain the CKM hierarchy?

1) tCPV in $B^0 \rightarrow \phi K^0, \eta' K^0, K_s K_s K_s$
2) tCPV in $B^0 \rightarrow K_s \pi^0 \gamma$
3) $B \rightarrow \tau \nu, \mu \nu, D \tau \nu$
4) $\tau \rightarrow \mu \gamma$
5) Unitarity triangle with $O(1)\%$ precision

Key measurements to answer questions above.
Unique at an e+e- B factory (difficult at a hadron machine)
New CP Violation in $b \to s$

2.6$\sigma$ (2006) from $\sin 2\phi_1$

$B \to \phi K^0, \eta'K^0, KsKsKs$ projection for SuperKEKB
• Mass reach in general is much higher than $O$(TeV).
SuperKEKB Projection for $B \rightarrow Ks\pi^0\gamma$

and other $b \rightarrow s(d)\gamma$ modes

$\begin{align*}
&b \quad m_b \\
&\downarrow \quad sL
\end{align*}$

$\begin{align*}
&m_s \\
&\downarrow \quad sR
\end{align*}$

SM expectation

$S \sim -2m_s/m_b \times \sin 2\phi_1$

NP with different chiral structure makes a large difference

Possible deviation from SM

- $O(1)$: Warped extra dim.
- $O(1)$: L-R symmetric model
- $O(0.1)$: SUSY SU(5)

Vertex detector with a larger radius preferred

$\delta S = 0.1 \rightarrow 3.3/ab$

$SVD2 \times 1.5$ (n-1)th lyr (16cm)

LoI 5th lyr (10cm)

SVD2 3rd lyr (7cm)
**B → τν results**

**Belle**

First evidence, 3.5 σ


Belle Hadronic tag

**Constraint on charged Higgs**

\[
\text{Br}(B \to \tau\nu) = \left(1.79 \pm 0.56^{+0.46}_{-0.49} \right) \times 10^{-4}
\]
**B → τν: Future Prospect**

**Charged Higgs Mass Reach**

(95.5% CL exclusion @ tanβ=30)

![Graph](image)

**Only exp. error**

(ΔV_{ub}=0%, Δf_B=0%)

ΔV_{ub}=2.5%, Δf_B=2.5%

ΔV_{ub}=5%, Δf_B=5%

\[
\mathcal{B}(B \to \tau \nu) = \frac{G_F^2 m_B}{8\pi} m_\tau^2 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B
\]
Full Reconstruction Method

- Fully reconstruct one of the B’s to tag
  - B production
  - B flavor/charge
  - B momentum

Equivalent to “single B meson beam”!

Decays of interests
- \( B \rightarrow X u l \nu \), \( B \rightarrow K \nu \nu \), \( B \rightarrow D \tau \nu , \tau \nu \)

full (0.1~0.3%) reconstruction \( B \rightarrow D\pi \) etc.

Powerful tools for B decays w/ neutrinos
Precise $B \rightarrow \tau \nu / \mu \nu$ data provide lepton universality test.
- Higgs effect itself is universal. $R_{H}^{\tau \nu} = R_{H}^{\mu \nu}$
- Good probe to distinguish NP models.

$SM$

$Br(\tau \nu) = 1.6 \times 10^{-4}$
$Br(\mu \nu) = 7.1 \times 10^{-7}$
$Br(e \nu) = 1.7 \times 10^{-11}$

$3\sigma$ at $1.6 ab^{-1}$
$5\sigma$ at $4.3 ab^{-1}$

→ good discovery channel at an early stage of SuperKEKB
\[ 5 \text{ ab}^{-1} \rightarrow M_H > \frac{M_W \tan \beta}{11} \]

\[ 50 \text{ ab}^{-1} \rightarrow M_H > \frac{M_W \tan \beta}{5} \]

- H-b-u vertex by \(B \rightarrow \tau \nu\)
- H-b-c vertex by \(B \rightarrow D\tau\nu\)
- H-b-t vertex by LHC direct search.

Very nice universality test for Higgs-quark couplings

Similar to \(B \rightarrow \tau \nu\)

50\text{ab}^{-1} \quad \Delta_{FF}=5\%

5\text{ab}^{-1} \quad \Delta_{FF}=15\%
LFV in $\tau$ decays and SUSY GUT

- $\text{Br} \sim O(10^{-9})$ at Super B factory

![Diagram showing accessible branching ratios versus luminosity with points representing different models and experiments.]

Goto-Okada-Shindo-Tanaka 2006

SU(5)+$\nu_R$ non-degenerate, $\mu_R = 4 \times 10^{14}$ GeV

$\tan \beta = 30$

Branching Ratio

$B(\mu \to e\gamma)$
Flavor symmetry?

Many proposals, not conclusive at the moment.
(Observed pattern consistent with many models)

- Example: Q6 (with SUSY)
  - 9 independent parameters to describe 10 observables (6 quark masses + 4 CKM parameters)

Testable (falsifiable) if sufficient precision obtained!
Precise $\phi_3$ measurements may play an essential role to be free from theory uncertainties
Unitarity Triangle Fit (50/ab)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Belle ($\sim 0.5\text{ab}^{-1}$)</th>
<th>SuperKEKB (50ab$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r_d^2$</td>
<td>$\pm 0.7$</td>
<td>$\pm 0.15$</td>
</tr>
<tr>
<td>$2\theta_d$</td>
<td>$\pm 11^\circ$</td>
<td>$\pm 3^\circ$</td>
</tr>
</tbody>
</table>
$B \rightarrow \pi\pi$ will be golden again

New!

$S(B^0 \rightarrow \pi^0\pi^0)$ with external photon conversion

8-fold $\rightarrow$ 2-fold ambiguity
Other studies included in the physics book

• Charm (D mixing etc.)
• Bs physics on Upsilon(5S)
• Upsilon physics (incl. dark matter search)
• Electroweak physics
• Charmed hadrons

• Improved theory descriptions
  – taking recent exp. results into account (e.g. Bs mixing)
<table>
<thead>
<tr>
<th>Observable</th>
<th>Belle 2006 (≈0.5 ab⁻¹)</th>
<th>SuperKEKB (5 ab⁻¹)</th>
<th>SuperKEKB (50 ab⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hadronic b → s transitions</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>$\Delta S_{f^+ K^0}$</td>
<td>0.22</td>
<td>0.073</td>
<td>0.029</td>
</tr>
<tr>
<td>$\Delta S_{f^+ K^0}$</td>
<td>0.11</td>
<td>0.038</td>
<td>0.020</td>
</tr>
<tr>
<td>$\Delta S_{K^0 K^0 K^0}$</td>
<td>0.33</td>
<td>0.105</td>
<td>0.037</td>
</tr>
<tr>
<td>$\Delta S_{K^0 K^0}$</td>
<td>0.15</td>
<td>0.072</td>
<td>0.042</td>
</tr>
<tr>
<td>$A_{\phi K^+}$</td>
<td>0.17</td>
<td>0.05</td>
<td>0.014</td>
</tr>
<tr>
<td><strong>Radiative/electroweak b → s transitions</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$S_{K^0 K^0}$</td>
<td>0.32</td>
<td>0.10</td>
<td>0.03</td>
</tr>
<tr>
<td>$R_K$</td>
<td>0.07</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>$\mathcal{B}(B \to X_s \gamma)$</td>
<td>13%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$A_{CP}(B \to X_s \gamma)$</td>
<td>0.058</td>
<td>0.01</td>
<td>0.005</td>
</tr>
<tr>
<td>$C_9$ from $\bar{A}_{FB}(B \to K^*\ell^+\ell^-)$</td>
<td>- 11%</td>
<td></td>
<td>4%</td>
</tr>
<tr>
<td>$C_{10}$ from $\bar{A}_{FB}(B \to K^*\ell^+\ell^-)$</td>
<td>- 13%</td>
<td></td>
<td>4%</td>
</tr>
<tr>
<td>$C_7/C_9$ from $\bar{A}_{FB}(B \to K^*\ell^+\ell^-)$</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\mathcal{B}(B^+ \to K^+\ell^+\ell^-)$</td>
<td>$^{\dagger\dagger} &lt; 9\mathcal{B}_{SM}$</td>
<td>33 ab⁻¹ for 5σ discovery</td>
<td></td>
</tr>
<tr>
<td><strong>Radiative/electroweak b → d transitions</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$S_{\tau\tau}$</td>
<td>- 0.3</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>$\mathcal{B}(B \to X_d \gamma)$</td>
<td>- 17%</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Leptonic/semileptonic B decays</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\mathcal{B}(B^+ \to \tau^+\nu)$</td>
<td>3.5$\sigma$</td>
<td>10%</td>
<td>3%</td>
</tr>
<tr>
<td>$\mathcal{B}(B^+ \to \mu^+\nu)$</td>
<td>$^{\dagger\dagger} &lt; 2.4\mathcal{B}_{SM}$</td>
<td>4.3 ab⁻¹ for 5σ discovery</td>
<td></td>
</tr>
<tr>
<td>$\mathcal{B}(B^0 \to D\tau\nu)$</td>
<td>- 7.9%</td>
<td>2.5%</td>
<td></td>
</tr>
<tr>
<td>$\mathcal{B}(B^0 \to D\nu)$</td>
<td>- 28.5%</td>
<td>9.0%</td>
<td></td>
</tr>
<tr>
<td><strong>LFV in $\tau$ decays</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\mathcal{B}(\tau \to \mu\gamma)$</td>
<td>$[10^{-6}]$</td>
<td>$&lt; 45$</td>
<td>$&lt; 30$</td>
</tr>
<tr>
<td>$\mathcal{B}(\tau \to \mu\eta)$</td>
<td>$[10^{-6}]$</td>
<td>$&lt; 65$</td>
<td>$&lt; 20$</td>
</tr>
<tr>
<td>$\mathcal{B}(\tau \to \mu\mu)$</td>
<td>$[10^{-9}]$</td>
<td>$&lt; 209$</td>
<td>$&lt; 10$</td>
</tr>
<tr>
<td><strong>Unitarity triangle parameters</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sin 2\phi_1$</td>
<td>0.016</td>
<td>0.016</td>
<td>0.012</td>
</tr>
<tr>
<td>$\phi_2(\pi\pi)$</td>
<td>11°</td>
<td>10°</td>
<td>3°</td>
</tr>
<tr>
<td>$\phi_2(\rho\pi)$</td>
<td>$68^\circ &lt; \phi_2 &lt; 95^\circ$</td>
<td>3°</td>
<td>1°</td>
</tr>
<tr>
<td>$\phi_2(\rho\rho)$</td>
<td>$62^\circ &lt; \phi_2 &lt; 107^\circ$</td>
<td>3°</td>
<td>1°</td>
</tr>
<tr>
<td>$\phi_2$ (combined)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\phi_3$ ($D^{(<em>)}K^{(</em>)}$)</td>
<td>20°</td>
<td>8°</td>
<td>4°</td>
</tr>
<tr>
<td>$\phi_3$ ($D^{(*)}\pi$)</td>
<td>- 16°</td>
<td>5°</td>
<td></td>
</tr>
<tr>
<td>$\phi_3$ ($DK^{(*)}$)</td>
<td>- 18°</td>
<td>6°</td>
<td></td>
</tr>
<tr>
<td>$\phi_3$ (combined)</td>
<td>7°</td>
<td>3°</td>
<td></td>
</tr>
<tr>
<td>$</td>
<td>V_{ub}</td>
<td>$ (inclusive)</td>
<td>7.3%</td>
</tr>
<tr>
<td>$</td>
<td>V_{ub}</td>
<td>$ (exclusive)</td>
<td>15%</td>
</tr>
<tr>
<td>$^{\dagger\dagger}\bar{p}$</td>
<td>29.0%</td>
<td>3.4%</td>
<td></td>
</tr>
<tr>
<td>$^{\dagger\dagger}\bar{\eta}$</td>
<td>15.7%</td>
<td>1.7%</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Observable</th>
<th>Belle 2006 (2 fb⁻¹)</th>
<th>Belle/SuperKEKB (500 fb⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_s$ physics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\mathcal{B}(B_s \to \gamma\gamma)$</td>
<td>$&lt; 0.53 \times 10^{-4}$</td>
<td>a few ab⁻¹ for 5σ discovery</td>
</tr>
<tr>
<td>$\mathcal{B}(B_s \to \phi\gamma)$</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$\phi_s$ (with $B_s \to J/\psi\phi$ etc.)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$\mathcal{B}(B_s \to \mu^+\mu^-)$</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$\phi_3$ ($B_s \to KK$)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$\phi_3$ ($B_s \to DK$)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$T$ decays</td>
<td>(3 fb⁻¹)</td>
<td>(500 fb⁻¹)</td>
</tr>
<tr>
<td>$\mathcal{B}(Y(1S) \to$ invisible)</td>
<td>$&lt; 2.5 \times 10^{-3}$</td>
<td>$&lt; 2 \times 10^{-4}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Observable</th>
<th>Belle 2006 (5 ab⁻¹)</th>
<th>Belle/SuperKEKB (50 ab⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charm physics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$D$ mixing parameters $[10^{-3}]$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\mathcal{x}$</td>
<td>3.4 (2.4$\sigma$)</td>
<td>1.6</td>
</tr>
<tr>
<td>$\mathcal{y}$</td>
<td>4.1 (3.2$\sigma$)</td>
<td>1.3</td>
</tr>
<tr>
<td>$\mathcal{x^2}$</td>
<td>0.22</td>
<td>0.07</td>
</tr>
<tr>
<td>$\mathcal{y}$</td>
<td>4.0</td>
<td>1.22</td>
</tr>
<tr>
<td>$R_M$</td>
<td>0.49</td>
<td>0.11</td>
</tr>
</tbody>
</table>

| New particles                   |                       |                            |
| Electroweak parameters          |                       | (≈1 ab⁻¹)                  |
| $\sin^2 \theta_W$              | -                     | $3 \times 10^{-4}$         |
Physics at Super B Factory: Summary

Elucidation of the pattern of flavor symmetry breaking (highly experiment-driven, seeking a new hypothesis on flavor)

- Effects of TeV new physics $\rightarrow$ deviations from SM
- LFV and new source of CPV
- Hidden flavor symmetry and its breaking

<table>
<thead>
<tr>
<th>Observable</th>
<th>$\Delta S(B\rightarrow\phi K^0)$</th>
<th>$S(B\rightarrow Ks\pi^0\gamma)$</th>
<th>M(H$^+$)</th>
<th>$\tau$ LFV</th>
<th>UT fit</th>
<th>Reach</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.03</td>
<td>0.03</td>
<td>$\sim$500GeV</td>
<td>O(10$^{-9}$)</td>
<td>O(1%)</td>
<td>0.03</td>
</tr>
</tbody>
</table>

($\sim$100TeV w/o suppression)
Integrated Luminosity Projection for SuperKEKB

- SuperKEKB is a natural extension of KEKB, the world leader on the luminosity frontier.
- $8 \times 10^{35}$ cm$^{-2}$s$^{-1}$ will be available with technologies proven at KEKB, together with a few modifications.
Part II

SOI Pixel R&D
a "dream" of detector physicist

1. (high Z) semiconductor sensor

with

2. fully integrated ampl. circuitry and R/O logic

using

3. commercially available CMOS technologies

---

SOI Monolithic Pixel Detector!

Silicon-On-Insulator
Advantages of SOI

- Full Dielectric Isolation: *Latchup Free, Small Area*
- Low Junction Capacitance: *High Speed, Low Power*
- No Well junction, Thin Film: *Low Leakage, Low Vth Shift (~300 °C)*
- Small Active Volume: *High Soft Error Immunity*
• SOI is regarded as the mainstream technology in industry in the near future. Rapid progress anticipated.
SOI Wafer Fabrication (UNIBOND™, SOITEC)

1. Initial silicon wafers A & B
2. Oxidation of wafer A to create insulating layer
3. Smart Cut ion implantation induces formation of an in-depth weakened layer
4. Cleaning & bonding wafer A to the handle substrate, wafer B
5. Smart Cut - cleavage at the mean ion penetration depth splits off wafer A
6. Wafer B undergoes annealing, CMP and touch polish => SOI wafer complete
7. Split-off wafer A is recycled, becoming the new wafer A or B

- CMOS (Low R)
- Sensor (High R)
- ~500°C
- hydrophilic bonding
- microbubbles
Features of SOI Monolithic Pixel detector

- Bonded Wafer (High Resistive Substrate + Low Resistive Top Si).
- Standard CMOS Electronics (NMOS, PMOS, MIM Cap etc. can be used).
- Monolithic Detector, No Bump Bonds (Lower cost, Thin Device).
- High density (Smaller Pixel Size is possible).
- Small capacitance of the sense node (High gain V=Q/C).
- Industrial standard technology (Cost benefit and Scalability).

Explore possibility of SOI detector for future experiments (ILC, SLHC, Super-Belle etc.) and other applications (Medical, Material etc.)
SOI Products and Applications

Performance

Mobile Computing
Digital AV

High-performance

Network

Mobile Phone
Mobile AV
WristProduct

PD-SOI

Rad-Hard,
High-temp.
High-reliability

Watch, Atomic Clock,
Sensor Network

Green Energy

RTC
Specific Sensor Applications

Oki FD-SOI

OKI CONFIDENTIAL
'05.4: Detector R&D workshop @KEK. Express interests on SOI Pixel.

5: Create SOIPIX group, and propose SOI Pixel R&D to KEK Detector Technology Project (Generic R&D).

6: Negotiate with OKI Electric Industry Co. Ltd.

7: Start SOI detector R&D with OKI.

10: First TEG designs submitted for 0.15μm SOI CMOS process.

'06.1: Characteristics of substrate p-n junctions were measured successfully. ENEXSS TCAD simulator was introduced.

3: Process of the 1st TEG chips was finished.
'06.4-7: Response to Laser light was measured in strip TEG.
First Picture was taken with 32x32 SOI Pixel.
Good response to Sr$^{90}$ β-ray was confirmed.
4-10: Presentation at conferences (SNIC06, STD6,
Vertex, LECC, NSS, JSP ...)
12: 2nd TEG Submissions by
Multi Project Wafer (MPW)
run with 17 designs.
'07.3 : 2nd TEG process is almost
finished. --> Test now!
SOIPIX collaborators

KEK Detector Technology Project: [SOIPIX Group]

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OKI Elec. Ind. Co.^H

(*)—contact person

Financial Support by KEK Detector Technology Project
<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMPTEG</td>
<td>Preamp, Time over threshold, comparator, active feedback etc.</td>
</tr>
<tr>
<td>RADTEG</td>
<td>Pixel, transistor, ring oscillator</td>
</tr>
<tr>
<td>PIXTEG</td>
<td>32x32 pixel array with readout</td>
</tr>
<tr>
<td>STRIPTEG</td>
<td>Short strip sensor</td>
</tr>
<tr>
<td>HAWAIITEG</td>
<td>Hard X-ray Compton polarimeter</td>
</tr>
</tbody>
</table>

Our fully-Depleted CMOS SOI TEG is fabricated by OKI Electric Industry Co. Ltd.
- commercial technology with 150nm rule
Pixel TEG

CMOS Active Pixel Sensor Type
20 µm x 20 µm
32 x 32 pixels
Pixel Layout

Window for Light Illumination (5.4 x 5.4 um²)

p+ junction

Storage Capacitance (100 fF)

Pixel Layout
Pixel first signal!

- $V_{\text{back}} = 5\text{V}$
- Flashlight

The ramp up speed depends on the light intensity.
Plastic Mask

Vdet = 10 V
Exposure Time = 7 µs

32x32 image view with 670nm Laser and plastic mask
\( V_{\text{sense}} = \frac{Q}{C} \approx \frac{0.6 \text{fC}}{8 \text{fF}} = 70 \text{mV} \)

\( V_{\text{det}} = 10 \text{ V} \)

\( W_{\text{depletion}} \approx 44 \mu\text{m} \)

\( Q \approx 3500 \text{ e} (0.6 \text{ fC}) \)

Expected signal amplitude was observed for \( \beta \)-ray.
Pixel I-V characteristic

**Breakdown:** $\approx 100V$

Hot Spot observed with infrared camera

→ Smooth the corner and move the ring inward for the new submission.
**Back Gate Effect**

Substrate Voltage acts as Back Gate, and changes transistor threshold.

Signal disappears at 16V

Consistent with SPICE simulation.
Summary for MPW 1

- **Signal observed from pixels as expected**
  - beta source, IR laser
- **First successful imaging**
- **Issues for the next round identified**
  - Breakdown voltage
  - Backgate problem

⇒ TCAD studies for improvements
What's TCAD?

- TCAD = Technology Computer Aided Design
  - Process simulation
  - Device simulation
- Finer design rule → more complicated processes, longer development time
- TCAD can reduce development time drastically and is necessary for semiconductor manufacturing today
- Why not for detector R&D!
TCAD tools used in our studies

- **ENEXSS (Environment for NExt Simulation System)**
  - Developed by Selete (Semiconductor Leading Edge Technologies, http://www.selete.co.jp/)
  - Full 3D process/device simulation!

- **Silvaco TCAD**
  - ATHENA (Process simulation): 2D simulation
  - ATLAS (Device simulation): 2D or 3D simulation

**ENEXSS example** 3D device simulation for SOI

SOI NMOS

source

gate

BOX

drain

α particle injection

source current

\[ T \]
Breakdown voltage simulation

Diode simulation structure

simulated depth = 130 µm

ENEXSS
3D process/device simulation

GraphIV0

~92V
Breakdown voltage simulation with different configurations

** Simulation with smaller pixels: lower breakdown voltages than the previous case

→ dodecagon shape for the new submission
Implantation energy

Higher implantation energy for the new submission
Choice of implantation ion

Breakeven voltage = +88.5V

Ion #1

Boron goes deeper; effectively same as higher beam energy

Ion #2

Ion #1 $\rightarrow$ Ion #2 for the new submission
P+ implantation to reduce back gate effect

Additional p+ implantation (with voltage fixed at 0V or with some "anti-bias") should help reduce the back gate effect.
FY06 SOI MPW Run

* 17 designs were submitted on
  Dec. 5, 2006
  2.4 mm x 2.4 mm --- 10 chips
  5.0 mm x 5.0 mm --- 6 chips
  10.2 mm x 10.2 mm --- 1 chip

<table>
<thead>
<tr>
<th>CountPix</th>
<th>Oki (TEG1)</th>
<th>Hawaii (KEK)</th>
<th>Strip (KEK)</th>
<th>Oki (TEG2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
<td>SOI CMOS 0.15 μm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pixel Size</td>
<td>50 μm x 50 μm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of Pixels</td>
<td>128 x 128</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chip size</td>
<td>10 mm x 10 mm</td>
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<td></td>
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<tr>
<td>Sensor</td>
<td>Monolithic (Si)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Read Out</td>
<td>16 bit Parallel (Addressable)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Counter</td>
<td>16 bit Binary</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Trigger Out</td>
<td>X[63:0] &amp; Y[63:0]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Count Rates</td>
<td>&gt;10MHz/pix (&gt;4GHz/mm²)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Will be delivered soon.
Future Issues

- **Wafer Thinning**
  --> Less material. Super-B, ILC...
- **3D Circuit**
  --> Higher density.
- **Prepare Radiation Hard Cell Library**
  --> for Super-B, SLHC, Satellite ...
- **More sophisticated structure (Avalanche ...) in SOI substrate ?**
- **Go to much fine process < 0.15 μm ?**
- **Larger Detector (Stitching?)**
- **Cost saving**
SOIPIX: Summary

- New R&D for SOI pixel detectors is active
- Encouraging results from first MPW
  - First pixel signals with beta source, IR laser
  - First successful imaging
- Issues for the next round identified. TCAD studies were performed to propose improved designs.
  - Breakdown voltage
  - Backgate problem
- No showstopper so far
- The 2\textsuperscript{nd} MPW will be completed soon.
  - Various designs, more users
  - 1\textsuperscript{st} “large” sensor (1cm x 1cm)
Backup Slides
Present flavor physics in one page

Elucidation of the pattern of flavor symmetry breaking (highly experiment-driven, seeking a new hypothesis on flavor)

Low-energy Effective Field Theory (EFT)*

\[ \mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + \frac{1}{\Lambda} \mathcal{L}_5 + \frac{1}{\Lambda^2} \mathcal{L}_6 + \ldots \]

\[ \mathcal{L}_{\text{SM}} = \mathcal{L}_{\text{gauge}} + \mathcal{L}_{\text{matter}} + \mathcal{L}_{\text{Yukawa}} + \mathcal{L}_{\text{Higgs}} \]

- U(3)^5 flavor symmetry broken by \[ L_{\text{Yukawa}} \]
  - \[ L, B \] “accidently” conserved
  - \[ CP \] broken
- No “flavor principle”
  - parameters in \[ L_{\text{Yukawa}} \] (mixings, masses) determined experimentally
- Mysterious pattern in CKM/masses
  - Hidden flavor symmetry?

\[ \Lambda/4\pi \sim O(1) \text{ TeV} \] to resolve Higgs quadratic divergence

- Sizable effects in flavor sector allowed (“no effect” is extraordinary)
- Fruitful synergy with energy frontier
- Violation of \[ L, B, CP \] (not protected by any principle) expected
  - can be discovered (with luck) “at any time”

*[e.g. D’Ambrosio-Giudice-Isidori-Strumia 2002]*
Prospects for Elementary Particle Physics

The Japan Association of High Energy Physicists (JAHEP)

October 25, 2006

(An excerpt)

We, the Japanese HEP community, recognize that physics at the energy frontier is of primary importance. With this understanding, we give the highest priority to the realization of the ILC. Before the ILC experiment commences, we will also promote flavor physics that is complementary to physics at the energy frontier. We should pursue the above two goals as a single master plan.

....

Based on these achievements, we will endeavor to make neutrino and kaon experiments at J-PARC successful, and promote an upgrade of the B factory to achieve a significant breakthrough in luminosity in order to explore new physics that emerges in the phenomena of b, c and τ decays.
**PD-SOI** (Partially Depleted)
- Thick SOI Thickness ($T_{SOI}$)
  - $\sim$0.1 - 0.2$\mu$m
- Depletion Layer $<$ $T_{SOI}$
- Large Floating body effect
- High Drive Current by Kink effect
  → High speed application
- Compatible Process with Bulk-Si

**FD-SOI** (Fully Depleted)
- Thin SOI Thickness ($T_{SOI}$)
  - $<$ 0.05$\mu$m
- Depletion Layer $>$ $T_{SOI}$
- Less Floating body effect
- Better Subthreshold Slopes
  → Low-$V_{th}$ is available
- Process Issues in thin-film SOI

Oki chooses FD SOI which has advantage in performance of low voltage operation