S15　　2010A5110、2010A1744

【ポスター発表】領域拡大フーリエ変換ホログラフィーイメージング法の開発

富士通/富士通研究所　淡路直樹　　BL16XU、BL25SU

近年、先端の放射光光源に加え、X線自由電子レーザーや卓上型X線レーザーの開発が進んでおり、これらのコヒーレント（干渉性）X線を用いたナノ材料分析への関心が高まっている。2004 年、Dr. Eisebitt はX線マスク・試料一体型の測定試料を用いた軟X線レンズレス・フーリエ変換ホログラフィー法を開発し、垂直磁化膜の磁気ドメイン・イメージングを報告した。[1]　その後、この方法はアレイ型リファレンスを用いたワンショット・イメージング[2]や、生物試料への適用[3]などに展開されている。一方、この方法を種々のナノ試料の測定に適用する場合の問題点は、一体型試料の作製が困難であること、試料の分析視野が横コヒーレンス長の制限等により約2 μm 径と狭いこと、さらに分析位置は固定されることである。今回、我々はX線マスク部と試料部を分離し、精密ピエゾステージにより、接触状態で相互に移動できる方法を開発した。その結果、視野の拡大や測定場所が選択できるとともに、X線マスクは再利用でき、試料の作製も容易になった。この方法を BL25SU において 778 eV の軟X線に適用し、Co/Pt 垂直磁化膜の磁気ドメインの広領域測定に成功した。一方、BL16XU において、5500 eV の硬X線を用いて、0.23ミクロン幅の　Cu配線の測定を試み、その断面イメージングに成功した。イメージ端部の 10～90%強度変化から評価した空間分解能は、軟X線では 42nm、硬X線では 75nm であった。[4]

本実験は、文科省 XFEL 利用推進プロジェクト、「物質のフェムト秒物理・化学現象解析のためのX線散乱計測技術」の一環として、東北大学、JASRI、富士通の共同で行った。

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領域拡大フーリエ変換ホログラフィーイメージング法の開発

○淡路直樹[1]、野村健二[1]、土井修一[1]
磯上慎二[2]、角田匡清[2]
児玉謙司[3]、鈴木基寛[3]、中村哲也[3]

[1]富士通株式会社
[2]東北大学
[3] *JASRI/SPring-8*

X-ray coherent imaging

Coherent sources

Synchrotron radiation
Table top high harmonic laser
X-ray free electron laser (XFEL)

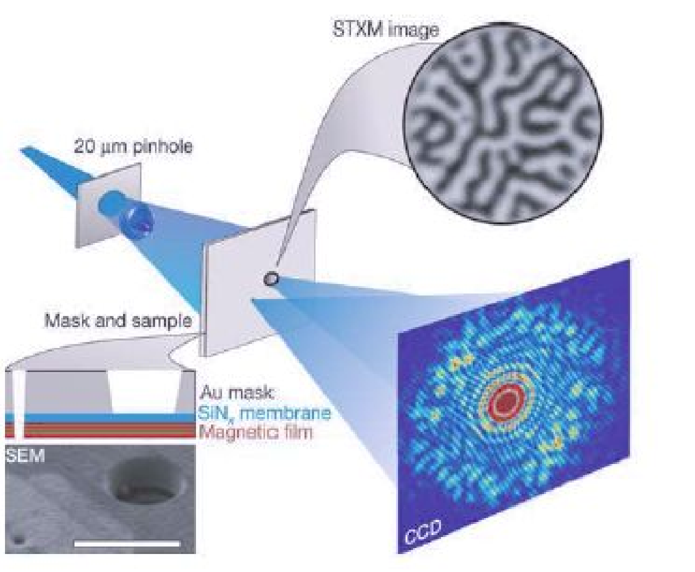
→

Application to Imaging

Nanomaterials
biological specimens

Fourier transform holography (FTH)

1974 S.Aoki and S.Kikuta, first x-ray hologram
Jpn. J. Appl. Phys. **13** (1974) 1385.
2004 S. Eisebitt et al., Observed magnetic domain using soft x-ray FTH
2008 S. Marchesini et al., Massively parallell x-ray holography: Nat. Photonics **2** (2008) 560.
2009 E.Guehrs et al., Biorogical specimens, Opt. Exp. **17** (2009) 6710.



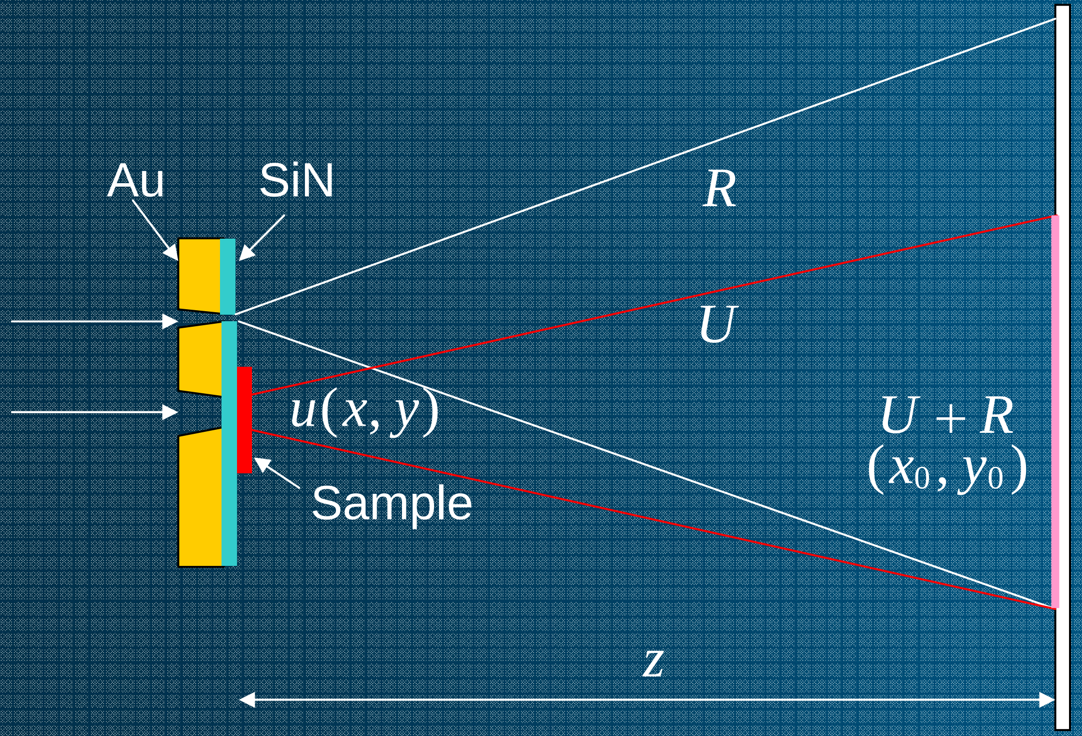
S. Eisebitt, J. Lüning, W. F. Schlotter, M. Lörgen, O. Hellwig, W. Eberhardt, and J. Stöhr,
Nature (London) **432** (2004) 885.

Technical features

- Simple image recovery
- 50nm spatial resolution (10-90%)
- Magnetic structure based on MCD effect

→ Suitable for one shot imaging

Lens-less FTH using integrated samples



$$|U+R|^2 = |U|^2 + |R|^2 + U \times R^* + U^* \times R$$

$$R(x_0, y_0) = \exp\left(ik \frac{(x_0^2 + y_0^2)}{2z} \right) \equiv C(x_0, y_0)$$

$$U(x_0, y_0) = \iint u(x, y) \frac{z}{r^2} \exp(ikr) dxdy$$

$$= C(x_0, y_0) \cdot FT(u(x, y))$$

$$U(x_0, y_0) \times R^*(x_0, y_0) = FT(u(x, y))$$

$$\therefore u(x, y) = FT^{-1}(U \times R^*)$$

Weak points as a microscope

Difficult sample preparation
Limited field of view (transverse coherence length ξ_T ~2µm)
Observation area can not be changed

Holography-mask and sample separated FTH

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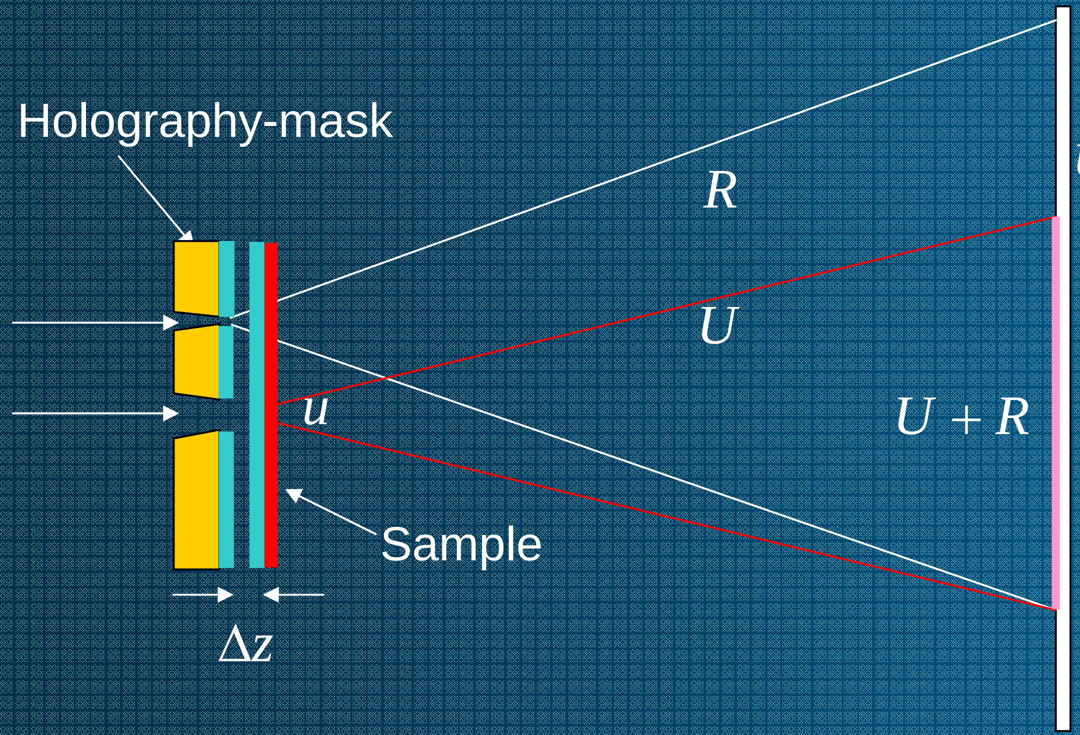


$$U(x_0, y_0) \times R^*(x_0, y_0) = \Delta C \times FT(u(x,y))$$

$$\Delta C(x_0, y_0) = \exp\left(ik \frac{(x_0^2 + y_0^2)}{2} \frac{\Delta z}{z(z+\Delta z)} \right)$$

$$\therefore u(x,y) = FT^{-1}(U \times R^* / \Delta C)$$

In case of finite Δz :

Need focus correction

Degradation due to finite ξ_L

Relative vibration

In contact: $\Delta z \to 0$

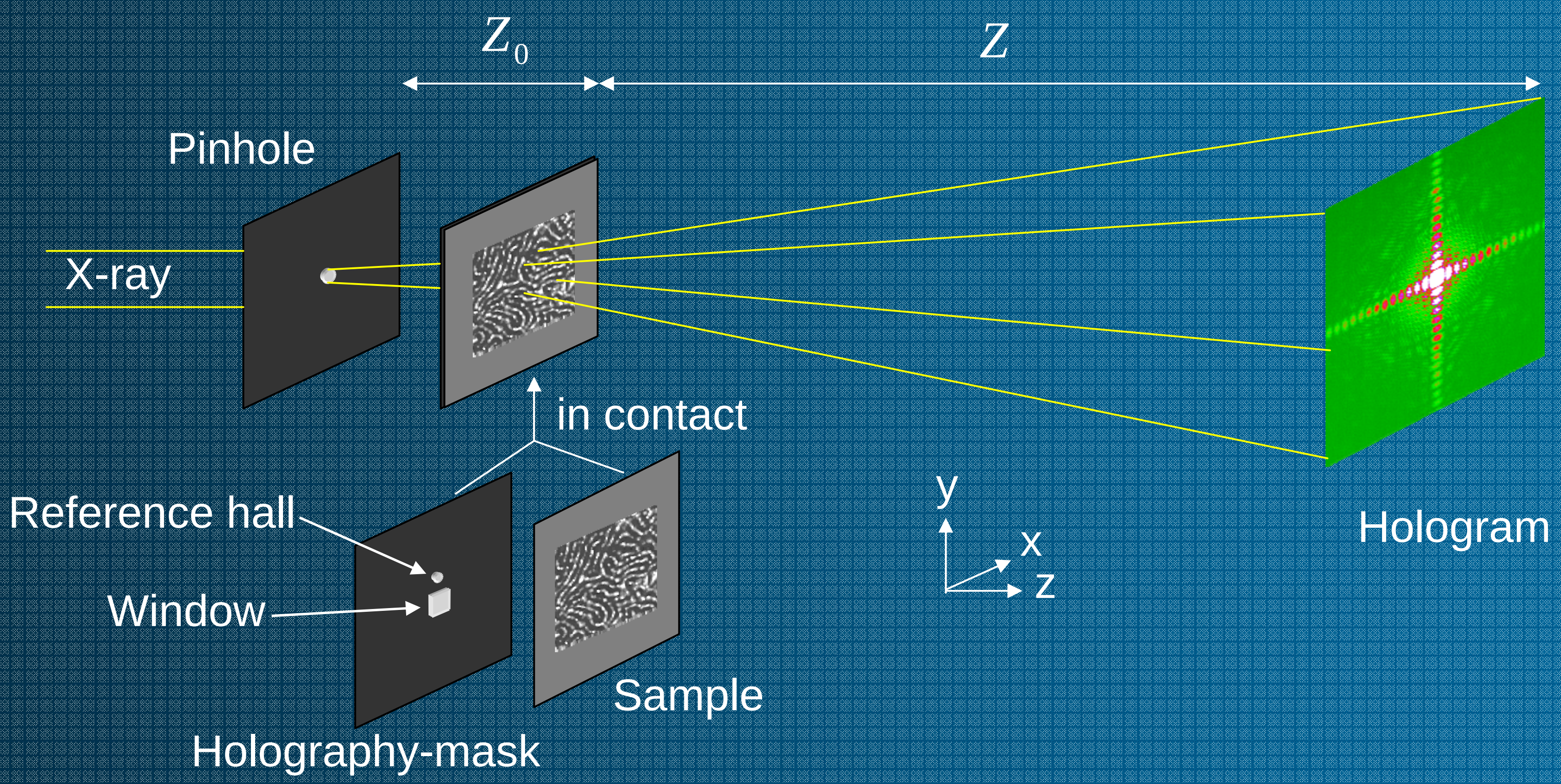
No focusing correction

No degradation by ξ_L

Suppresses relative vibration

⇨ **We chose contact mode**

Experimental configuration



Soft x-ray FTH of Co/Pt magnetized film

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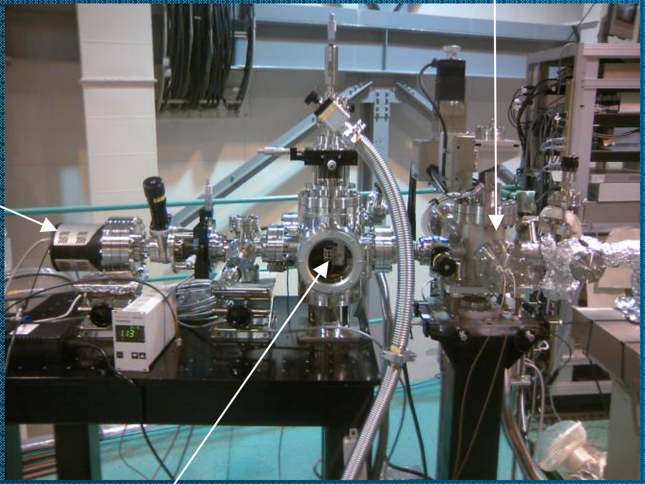
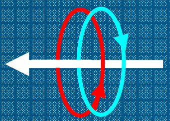
Charge structure &
Magnetic structure (MCD)

Pinhole/shutter

CCD
PI-SX2048B



Circularly polarized soft x-ray
SPring-8 BL25SU



Piezo-stage
ANT200/RT/UHV/NUM

Co L3 edge: 778 eV

$Pinhole = 20\mu m$

$Z_0 = 370mm$

$Z = 496mm$

Magnetic domain of Co/Pt film

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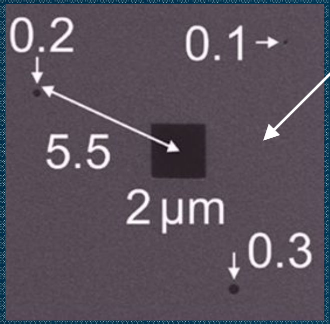
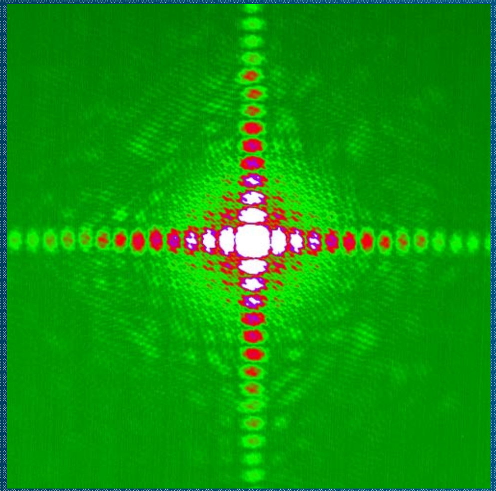
1.7μm thick Au



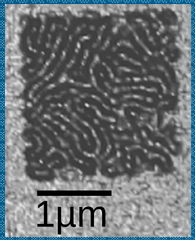
Holography-mask



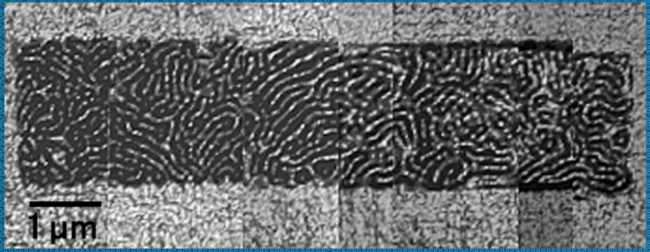
Holograms

invFFT

Image$_R$ - Image$_L$

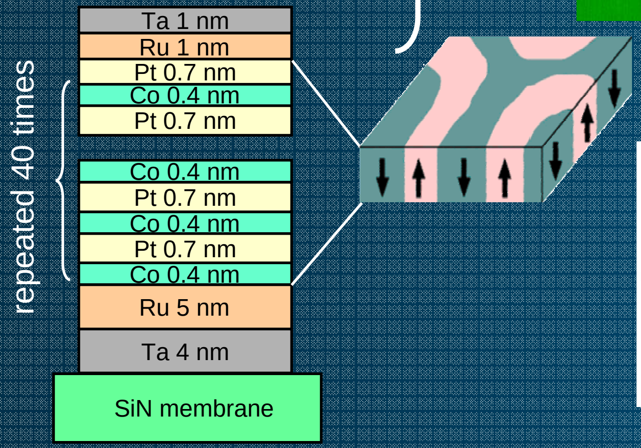


7 images

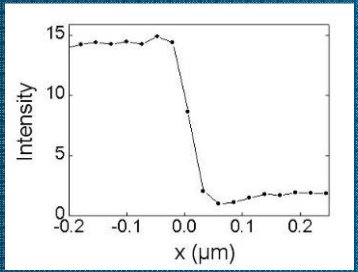


Succeeded in obtaining 8 μm Image (A bird's-eye view)

N. Awaji et. al.,
Appl. Phys. Express, 3, (2010) 085201.



Sample



Edge response

Spatial resolution
42nm (10-90%)

Recent report using a circular shaped window: D. Stickler et al., Appl. Phys. Lett. **96** (2010) 042501.

Hard x-ray FTH

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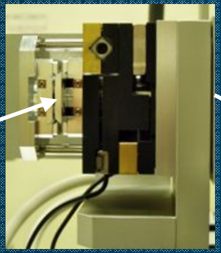
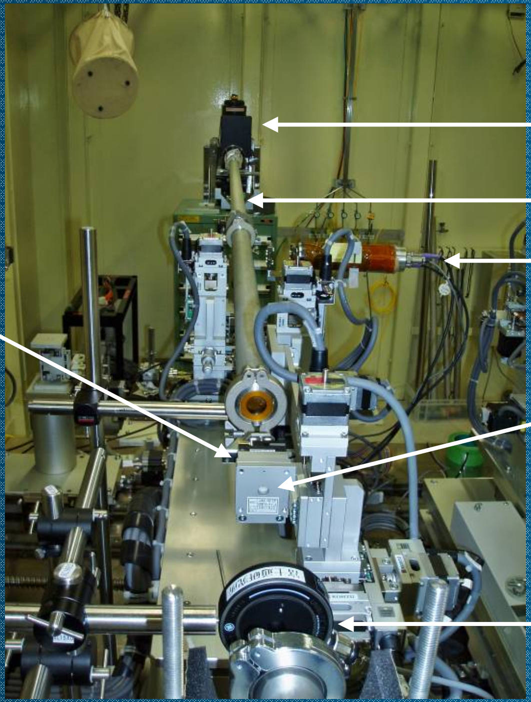
High penetration power
Measurement in the air

Sample



Piezo-stage
ANT200/RT/NUM



CCD(PI-LCX1300)

Vacuum pipe

Photomultiplier

Pinhole

Shutter

Undulator x-ray of SPring-8
BL16XU (SUNBEAM)

Energy = 5500 eV

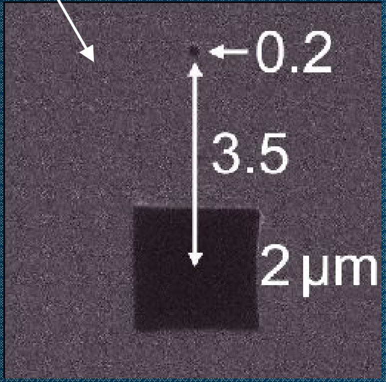
$Pinhole = 10\,\mu m$

$Z_0 = 50mm$

$Z = 3040mm$

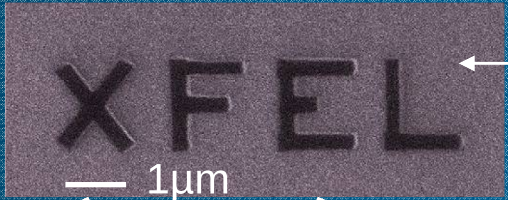
Artificially patterned sample

3.4µm thick Au

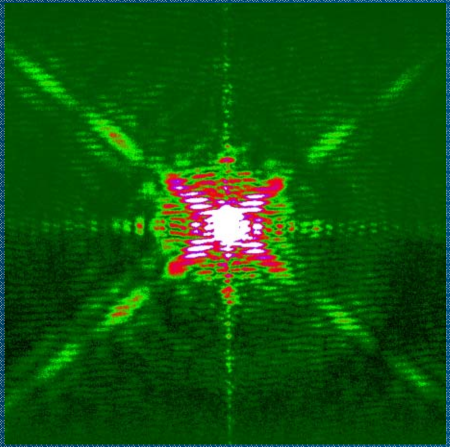


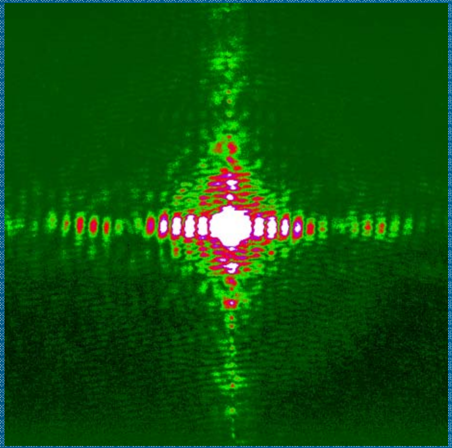
Holography-mask

SEM image of artificially patterned sample



1.7µm thick Au





Holograms

Combined 5 images

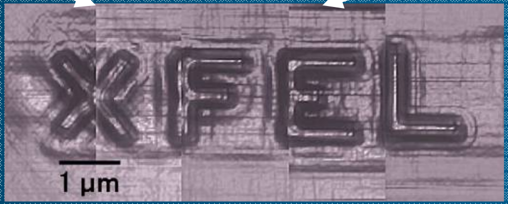
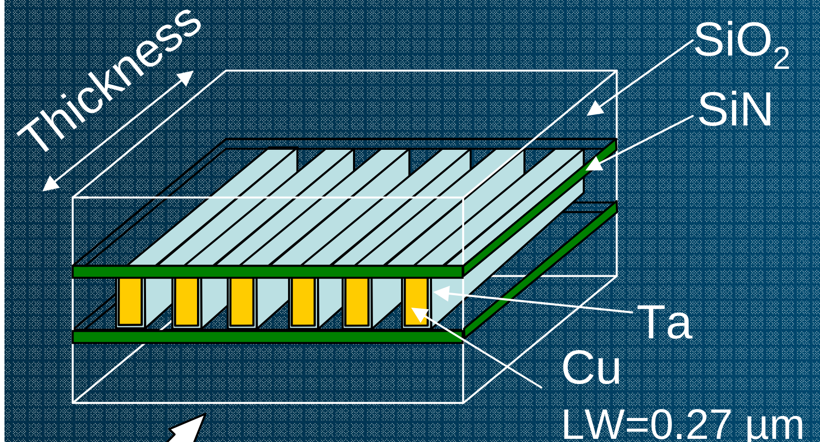
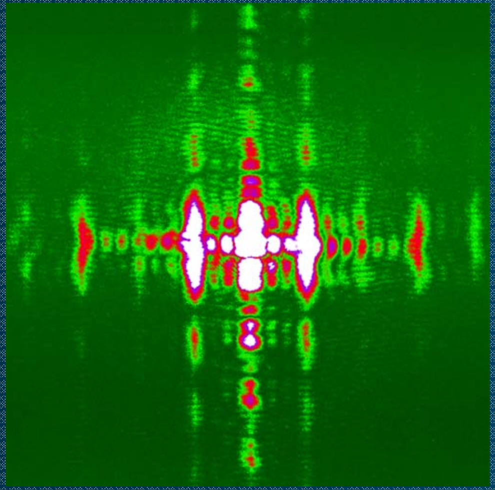


Image of 7 µm area
(A bird's-eye view)

Cross sectional image of Cu-interconnect-line

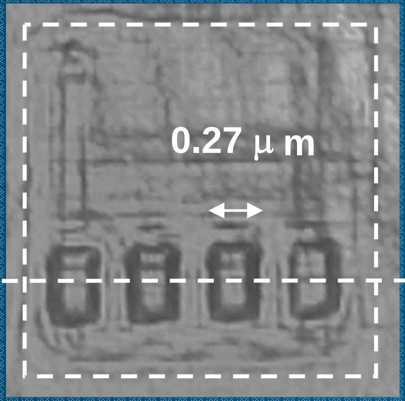


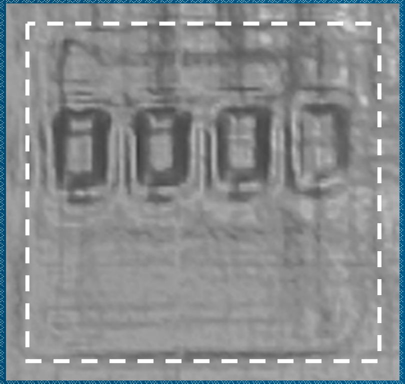
Cu-line structure
(Cross section)



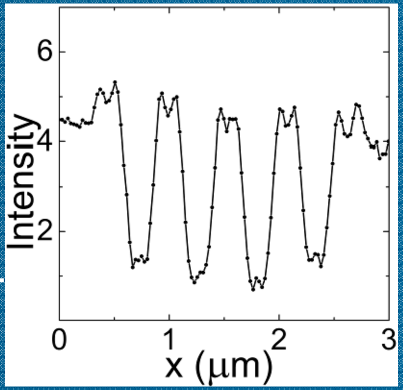
Hologram

2 µm thick sample





Reconstructed image
(A bird's-eye view)

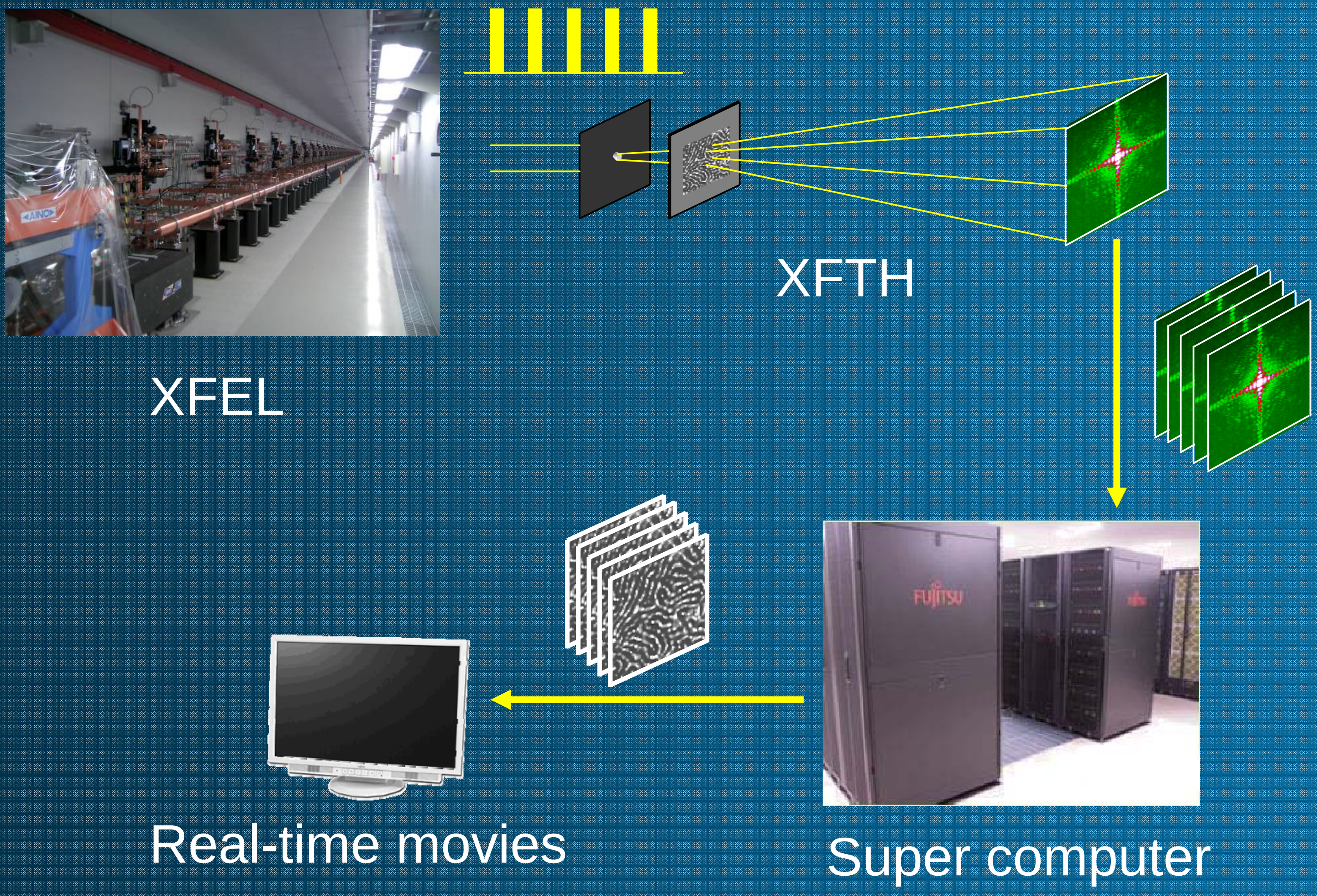


Line intensity on the
Cu cross section

⇩

Spatial resolution
75 nm (10-90%)

In the future



Summary and Conclusion

We succeeded in large area FTH imaging in both soft x-ray and hard x-ray.

The obtained spatial resolution of the image was 42 and 75 nm at 778 and 5500 eV, respectively.

N. Awaji et. al.,Appl. Phys. Express, 3, (2010) 085201.

An arbitrary selectable view area of this method in addition to the robust imaging based on FTH will provides the realtime imaging for nanomaterials and biological specimens in the future.

The experiments were performed at BL25SU and BL16XU in SPring-8 with the approval of the Japan Synchrotron Radiation Research Institute (JASRI) under proposal Nos. 2008A1513, 2009A1840, 2009B1844, and 2009B5110. This study was supported by the promotion program of XFEL research by ministry of education, culture, sports, science and technology (MEXT).