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Superconductivity in AuNiGe Ohmic contacts to a GaAs-based high mobility two-dimensional electron gas

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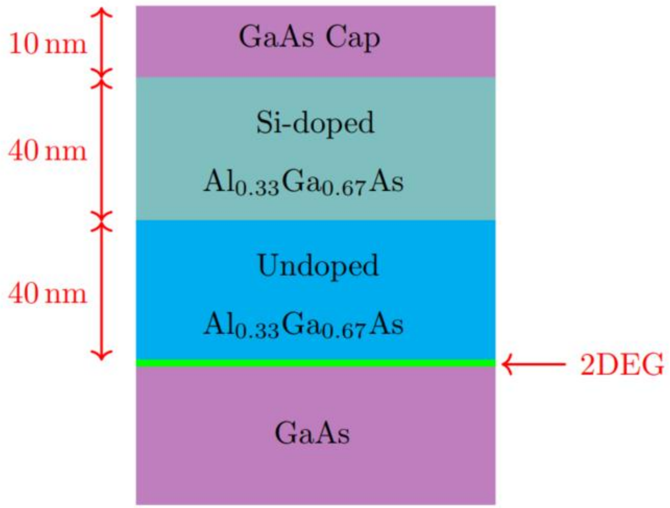
Overview

- Sample structure
- Hall measurements
- Contact & 2DEG resistance vs temperature
- Surface resistance $R_{top} \rightarrow$ SC
- Vertical resistance $R_V \rightarrow$ SC
- Ohmic formation, material analysis
- Potential SC compounds in contacts

Sample structure/processing

Wafer structure

- 3 wavers, same MBE structure
- 2DEG depth 90nm
- Si-doping: 1.5-1.65*$10^{18}cm^{-3}$
- Ohmic: Anneal in RTA 80s, 430°C in forming gas (N_2+H_2)



Growth: Cambridge University

- Ian Farrer (W476)
- Harvey Beere (V827, V834)

Wafer(s)	Batch	Metal deposition method	Layer thicknesses
W476	I	Eutectic	Total thickness=160 nm Au:Ge:Ni=83:12:5 wt%
V834 and V827	II	Layered	Total thickness=349 nm Ni/AuGe/Ni/Au= 3 nm/136 nm/30 nm/180 nm
V834	III	Layered	Total thickness=344 nm Ni/AuGe/Ni/Au= 0 nm/130 nm/50 nm/164 nm
V834	IV	Layered	Total thickness=353 nm Ni/AuGe/Ni/Au= 0 nm/123 nm/30 nm/200 nm

AuGe eutectic: 88% Au, 12% Ge (weight)

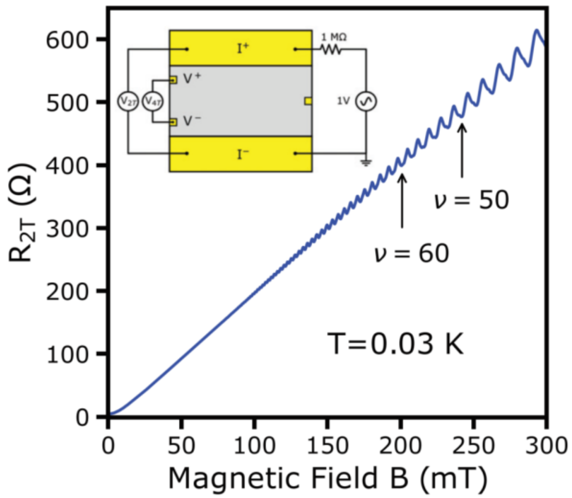
Figure	Sample	Device	Wafer	Batch
Figs. 1(a) and (b)	A	4mm×4mm	W476	I
Figs. 2(a)-(d)	B	4mm×4mm	V827	II
Fig. 3 (b)	C	TLM	V834	III
Fig. 3 (c)	D	TLM	V834	IV
Fig. 3 (d)	E	TLM	V834	II
Fig. 4	F	4mm×4mm	V834	II
Fig. S3		TLM	V834	III
Fig. S4		4mm×4mm	V834	II

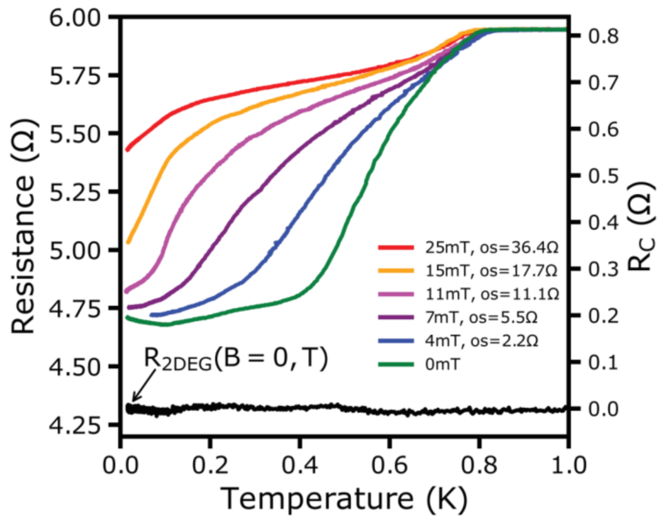
Ohmics become SC below 0.9K

Sample A: 4mm*4mm, 2mm*4mm 2DEG, 1.2mm separation 4T contacts

Ohmics: 160nm AuNiGe eutectic %wt: 83% Au, 5% Ni, 12% Ge

Mobility: $\mu = 2 \cdot 10^6 cm^2/Vs$ (4.2K after illumination)
SdH above 100mT
$n_{2D} = 3 \cdot 10^{11} cm^{-2}$ (Hall slope / indexed SdH)
$R_{sh} = 10\Omega/\blacksquare$





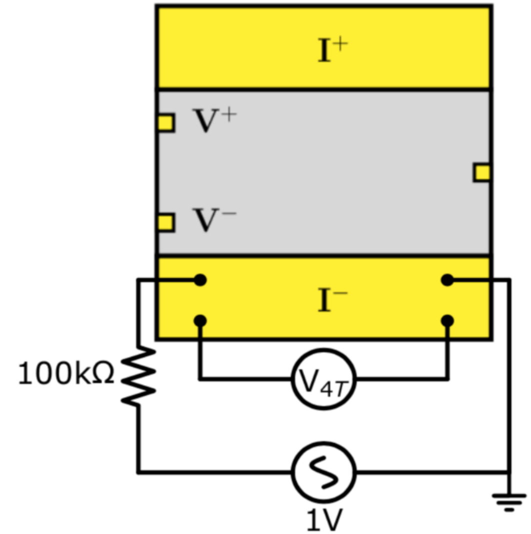
- Measurement: Current bias 1V V_{AC}, 1MΩ => 1μA
- Contact resistance: $R_{2T} = 2R_C + R_{2DEG} = 2R_C + \frac{2}{4} R_{sh} = 2R_C + \frac{5}{3} R_{4T}$

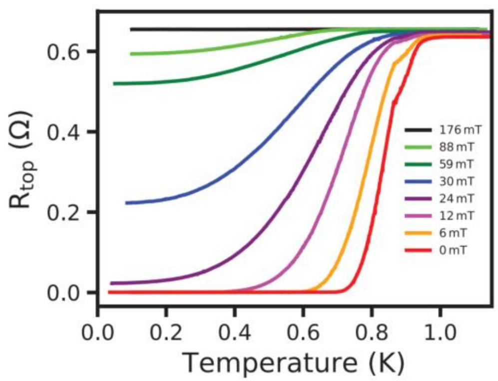
$$R_{4T} = \frac{1.2}{4} R_{sh}$$

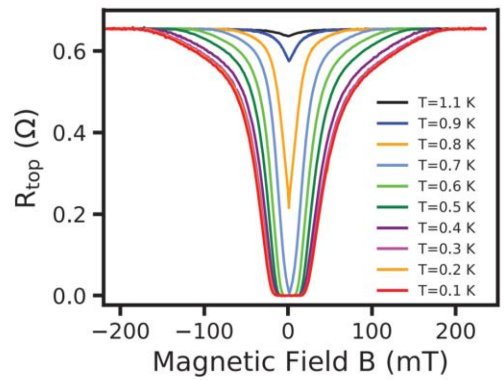
$R_{2DEG}(B = 0, T) \sim 4.3\ \Omega$
$R_C(B = 0, T) \sim 0.8\ \Omega$ above 0.9 K
$R_C(B = 0, T) \sim 0.2\ \Omega$ at low T

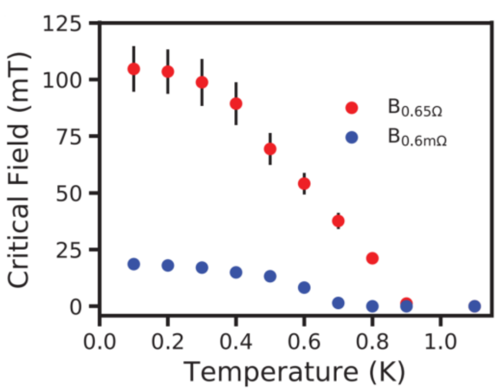
Ohmic surface resistance

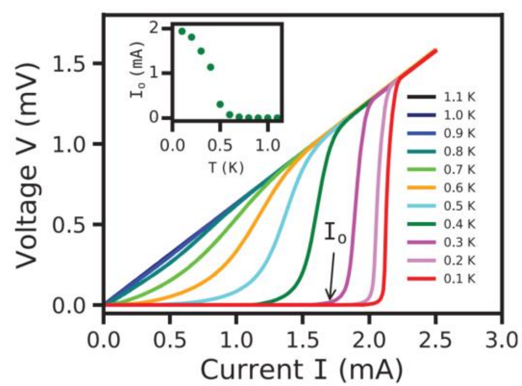
- Investigate different parts of Ohmic
- Surface: 4 Bonds on current contact → 4T meas. of pad
- Zero resistance at low T, T_C~ 0.9K
- Critical field $B_{||}$ ~ 150mT
- Phase diagram → T_C~ 0.9K
- Critical current $I_C(T_{base})$ ~ 2mA





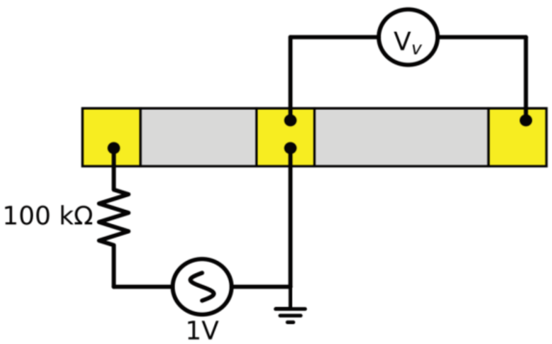


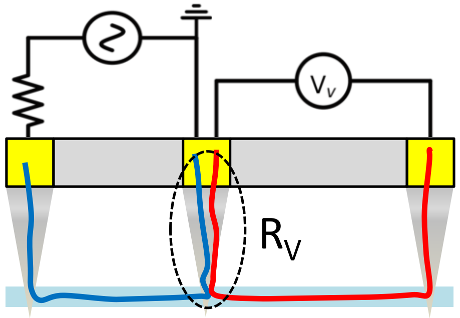


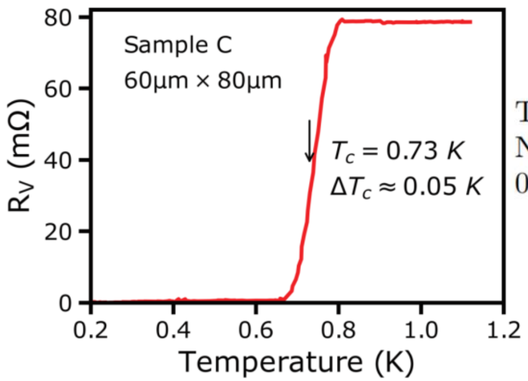


Ohmic vertical resistance

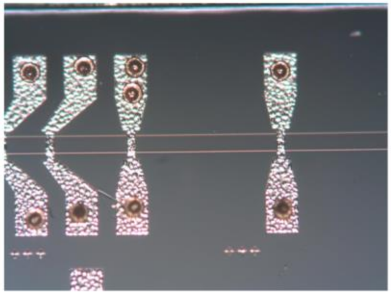
- Investigate different parts of Ohmic
- Vertical: Nonlocal meas. geometry
- $R_V \ll R_C$
- All 3 samples become SC
  (same wafer, different Ohmic recipe)
- Multiple T_C for sample D

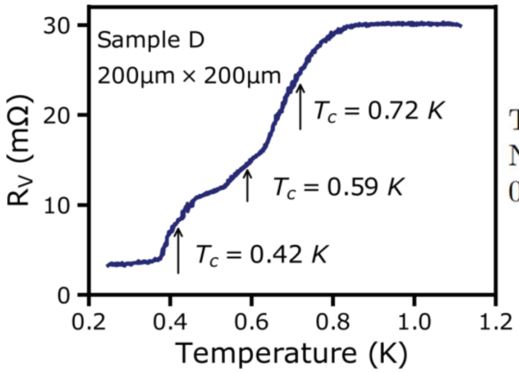






Total thickness=344 nm
Ni/AuGe/Ni/Au=
0 nm/130 nm/50 nm/164 nm





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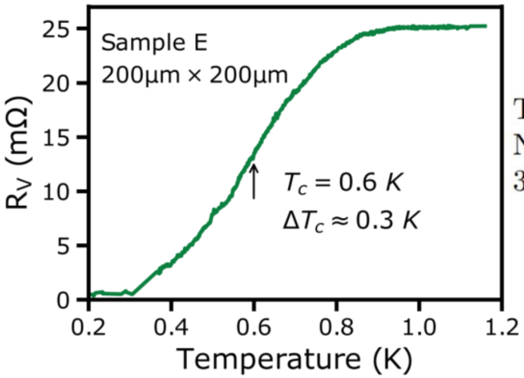


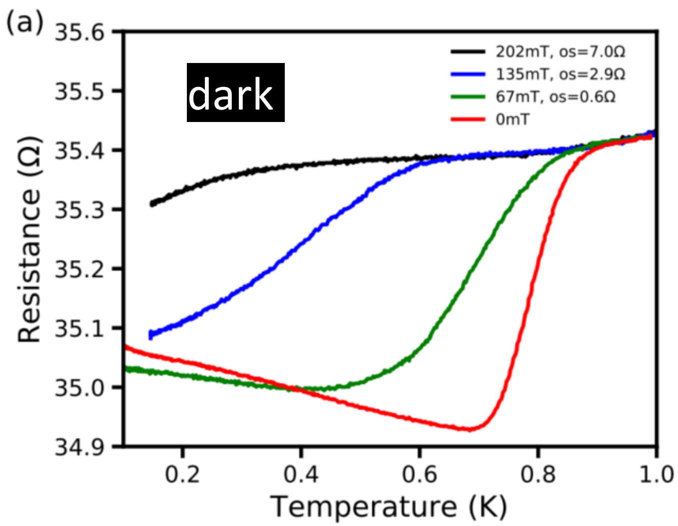
Total thickness=349 nm
Ni/AuGe/Ni/Au=
3 nm/136 nm/30 nm/180 nm

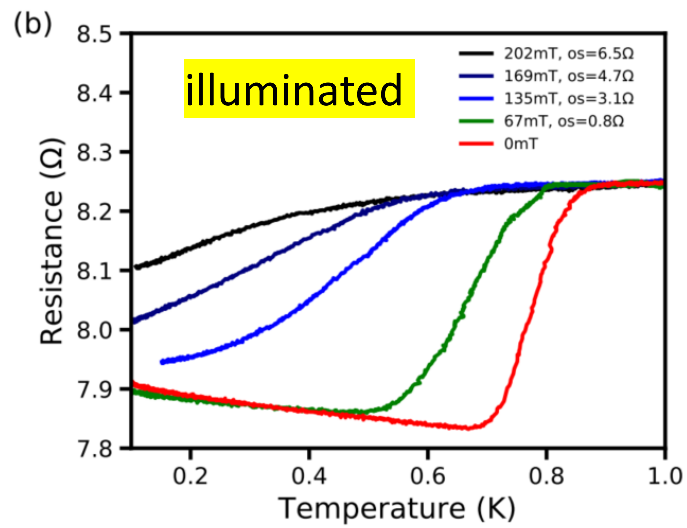
Parallel B-field, dark/illumnated

- 2T measurement → 2DEG + Ohmic
- Small magnetoresistance for B_{II}
- Resistance drop ~ 0.5 Ω
- B_C ~ 200mT (150mT for B_{perp})

Device details

V834	II	Layered	Total thickness=349 nm Ni/AuGe/Ni/Au= 3 nm/136 nm/30 nm/180 nm





n_{2DEG} & μ grow, R_{2DEG} drops

General trends

- AuNiGe Eutectic: broadest transitions (batch I)
- Batch II, III highest Tc, narrowest transition
- R_{top}, R_V above T_C constant up to 20K (disordered alloy)
- T_C and drop in R_{top}, R_V, R_C similar before/after illumination (not a 2DEG property)

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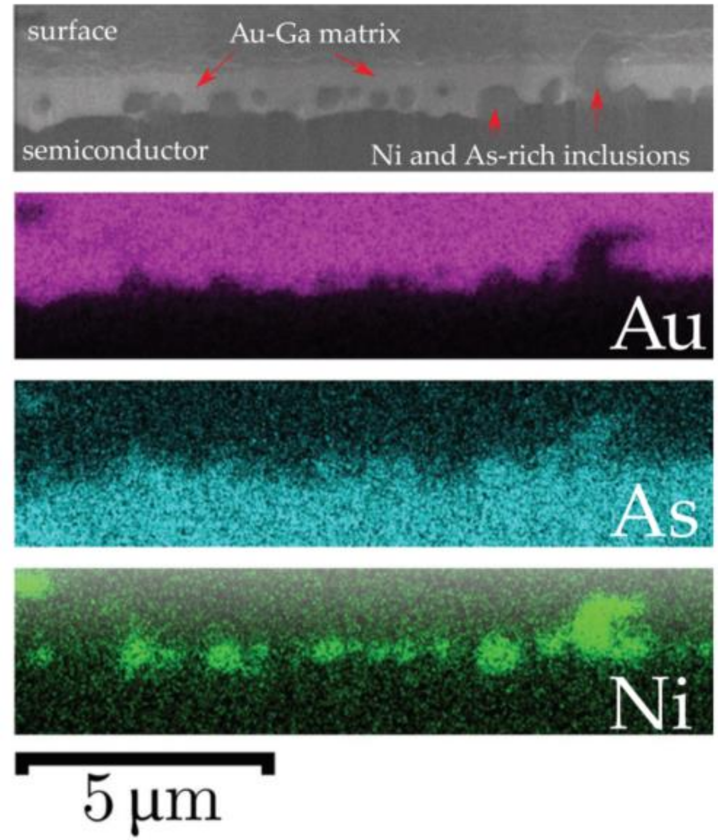
Eutectic: 88% Au (weight)

Formation of Ohmics

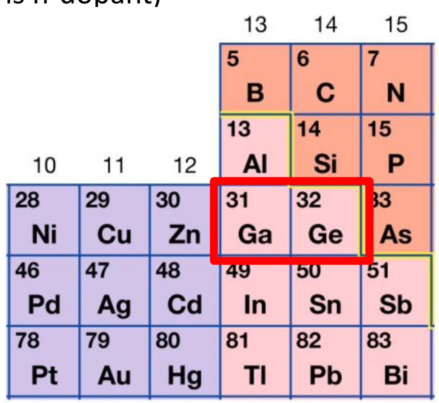
Good Ohmics

- 2DEG depth
- thickness AlGaAs layer
- sequence, thickness, composition of contact metal layers
- RTA temperature & time
- 2DEG mobility
- Surface quality before deposition



Ohmic formation

1. Ge compounds with Ni, As
2. Diffusion into GaAs
3. Replace Ga (Ge is n-dopant)
4. Ga up-diffusion
5. Au-Ga alloys



- β-AuGa most commonly observed, not SC
- Other known Ga based SC alloys:

AuGa:	T_C=1.1K	B_C=6mT
$AuGa_2$	T_C=1.63K	B_C>>10mT
α-Ga	T_C=0.9K	B_C=6mT

Superconducting compound?

- Elements/compounds in AuNiGe Ohmics
- Combinations of Au, Ni, Ge, Al, GaAs

Material	Present in AuNiGe ohmic? (Y or N)	Superconducting properties: T_c and B_c
α-AuGa	Y[19, 4]	0.008-0.264 K[5]
β-AuGa, Au_7Ga_2	Y[20, 21, 22, 4, 23, 3, 24, 25, 26, 27]	
Au_4Ga	Y[6, 7]	
Au_2Ga	N	
AuGa	N	1.24-1.3 K, 30 mT [14, 8, 28]
$AuGa_2$	Y[29]	1.7 K, 30 mT[8, 13, 28]
α-Ga	Y [2]	1.083 K, 5.8 mT[11]
β-Ga	N	6.04 K, 57 mT
Au(Ge,Ga)	Y[3]	
AuGe	Y[15, 16]	3.1 K[17]
Au/Ge layered	N	0.6-0.8 K[18]
Al	N	1.175 K, 10.5 mT
α-AuAl	N	0.008-0.385 K[5]
$AuAl_2$	N	0.18 K, 1.2 mT[13, 30, 31]
Au_4Al	N	0.3-0.7 K[14]

$\rightarrow$ Need full structural study to determine SC compound in contact

Summary

- Investigation of Ohmics on high-mobility 2DEG
- SC transition observed below ~0.9K in all samples with B_C~150mT
- Separately determine R_V, R_{top}, $R_V \ll R_{top}$, both become SC
- Many SC AuGa alloys exist (Ge down-diffusion, Ga from up-diffusion)
- Precise structure analysis needed to determine exact compound
- Cooling 2DEG to ultra-low temperatures:
  - apply 200mT field to break SC
  - use other Ohmic material, e.g. PdGe (PdGa alloys not known to be SC)